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DESIGN, DEVELOPMENT, AND FABRICATION OF FMU-35/B BOMB FUZE

HONEYWELL INC.
ORDNANCE DIVISION

TECHNICAL REPORT AFATL-TR-67-80

JULY 1967

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AIR FORCE ARMAMENT LABORATORY
AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE
EGLIN AIR FORCE BASE, FLORIDA

DESIGN, DEVELOPMENT, AND FABRICATION

of

FMU-35/B BOMB FUZE

R. L. Cordes

T. B. Sands

FOREWORD

This final report documents work done by Honeywell Inc., Ordnance Division, Hopkins, Minnesota, for the Air Force Armament Laboratory, Eglin Air Force Base, Florida under Contract AF 08 (635)-3745. Contract AF-3745 was granted by the sponsor on 17 June 1963 following a submittal of a proposal by Honeywell Inc. on 6 May 1963 in response to Eglin Air Force Base Purchase Request ASQW 63-426. The Air Force program monitor was Mr. James E. Wetzel (ATDF).

The research, design, and development tasks, inaugurated 17 June 1963 and concluded 1 January 1967, were accomplished under AFSC Program Element Number 63406124 and AFSC Project Number 2517. Honeywell Inc. acknowledges the invaluable assistance rendered throughout the program by various personnel of the Eglin Air Force Base.

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This technical report has been reviewed and is approved.

John H Hobaugh
JOHN H. HOBAUGH, Colonel, USAF
Chief, Development Division

ABSTRACT

Under Contract AF 08(635)-3745, initiated on 17 June 1963, an electronic, long-delay bomb fuze, the FMU-35/B, was to be designed, developed, fabricated, and evaluated. By its development, the inherent disadvantages of the mechanical fuze, viz., unsuitability for supersonic flights and deliveries, low reliability, and potential safety problems, were to be overcome. In the design and development of the fuze, those subassemblies of the existent FMU-26/B Bomb Fuze generically common to the FMU-35/B Bomb Fuze were modified, where necessary, for adaptation in the latter configuration. Through comprehensive programs of development, qualification, and Air Force engineering evaluation tests and through a comprehensive failure-analysis program, it has been possible to fabricate a long-delay fuze possessing a reliability in excess of 0.9 at a 90-percent confidence level. Concomitant with the engineering-evaluation program (Phase III), an E-Cell concept for adaptation to the FMU-35/B fuze was designed and developed. The innate simplicity of the E-Cell timer as a substitute for the electronic-timer subassembly in the FMU-35/B, and its initial evaluative successes justify further consideration of the E-Cell concept.

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LIST OF ABBREVIATIONS, SYMBOLS, AND ACRONYMS

A-D Switch = Anti-Disturbance Switch

BFD = Battery Firing Device

Bimag = Binary magnetic

Ckt. = Circuit

Cktry. = Circuitry

DD Form = A form used by two or more agencies or departments of the Department of Defense

ET = Explosive Train

FAR = Failure Analysis Report(s)

FMU = Munition Fuze Unit

g = Acceleration due to gravity, roughly equal to 980 cm/sec^2

gm = gram(s)

Hz = Hertz, a unit of frequency equal to one cycle/sec

HE = High explosive

iaw = In accordance with

KIAS = Knots Indicated Air Speed

MER = Multiple Ejection Rack(s)

μa = Microampere(s)

μs = Microsecond(s)

ma = Milliampere(s)

ms = Millisecond(s)

R&D = Research and Development

S/N = Serial number

vdc = Direct-current voltage

$\leq$ = Less than or equal to

$\geq$ = Greater than or equal to

SECTION I

INTRODUCTION

A. BACKGROUND

At the time of the contract, fuzes used to initiate high-explosive bombs possessed a number of disadvantages, the more serious of which were:

Unsuitability for Supersonic Flights and Deliveries - Aerodynamic buffeting at supersonic speeds rendered propeller arming and fuze-to-aircraft electrical connections susceptible to malfunctions. In addition, supersonic speeds subjected fuzes not enclosed in a bomb to heating problems.

Low Reliability - Bomb impacts subjected mechanical fuzes to high-g loads which caused timer failures, and low temperatures (-40° F to -65°F) adversely affected timer operation.

Potential Safety Problems - Mechanical-fuze designs did not assure a safe separation distance between the bomb and aircraft prior to arming.

The Honeywell Ordnance Division, in response to a Request for Proposal, Purchase Request ASQW63-426, for an electronic, long-delay bomb fuze, submitted a proposal to Eglin Air Force Base, Florida, on 6 May 1963. Honeywell proposed to use a number of then-recent design and developmental achievements in the FMU-26/B Bomb Fuze and FMU-30/B Mine Fuze. A contract, AF 08(635)-3745, was negotiated, and became effective on 17 June 1963.

B. OBJECTIVES

The assigned staff began its tasks on the day of contract effectivity to accomplish the three phases of the proposed Scope of Work, summarized as follows:

Phase I (The Design and Development Phase)

- Design and develop an electronic, long-delay bomb fuze suitable for employment in new-series munitions.
- Fabricate six fuze systems and test for compliance with Exhibit ASQW63-51.

Phase II (The Qualification and Field-Testing Phase)

- Fabricate 150 fuze systems and test them to assure compliance with Exhibit ASQW63-51.
- Provide one set of 35 mm slides showing fuze components, circuit diagrams, subsystems, and the complete assembly.
- Provide a functional demonstration model of the fuze containing visual indication of fuze arming and functioning.

Phase III (The Air Force Testing Phase)

- Fabricate 400 fuze systems for utilization by Eglin Air Force Base in engineering evaluation tests.
- Prepare final documents (Class I drawings, parts lists, specifications, and final summary report).
- Prepare final sets of 35 mm slides.

In order to accomplish the fuze design and developmental tasks outlined above, these problems had to be resolved:

- Prevention of functioning of the safing switch until the fuze is ready for installation into the fuze well. Required for the problem resolution: modification of the safing switch used in the FMU-26/B fuze.
- Provision of an explosive train which is functional in a long-delay-type fuze. Required for the problem resolution: modification of the explosive train used in the FMU-26/B fuze.

- Provision of an anti-withdrawal feature which will prevent de-arming and withdrawal of the fuze prior to the set function time. Required for the problem resolution: design and development of an anti-disturbance switch.

- Provision of an electronic package which is functional in a long-delay-type fuze. Required for the problem resolution were: (a) design and development of an oscillator with a frequency output greater than that of the oscillator used in the FMU-26/B fuze and (b) design and development of logic circuitry which will provide the specified range of set function times.

- Provision of a power supply which is functional in a long-delay-type fuze. Required for the problem resolution: design and development of a battery which will provide an output voltage for a time period greater than the maximum set function time.

C. PLAN OF THE REPORT

The report covers efforts from 17 June 1963 to 1 January 1967 to design, develop, and test an electronic, long-delay bomb fuze. Section II explains the purpose of the work undertaken, the course of action taken, the results obtained, the conclusions reached, and the recommendations offered. Sections III through VII describe the technical details of the contractual efforts. Section III describes the design and development of the fuze subassemblies and the final assembly. Section IV continues the narration of the technical details and contains information on the testing programs conducted during the contract. Sections V and VI describe the work performed in the reliability-engineering and the value-engineering programs. Section VII describes the design, development, and testing programs of the E-Cell Timer modification of the FMU-35/B fuze. The last section contains the conclusions of Honeywell engineering personnel and the recommendations they made to optimize the end item.

SECTION II

SUMMARY

The FMU-35/B Bomb Fuze (an electronic long-delay bomb fuze) was developed under Contract AF 08(635)-3745 to eliminate the disadvantages of current mechanical fuzes, viz., unsuitability for supersonic flights and deliveries, low reliability, and potential safety problems. The contractor's activities, beginning 17 June 1963, were carried out in three phases as follows:

- Phase I (Design and Development)
- Phase II (Qualification and Field Testing)
- Phase III (Air Force Testing)

In the design and development of the fuze, those subassemblies of the existent FMU-26/B Bomb Fuze common to the FMU-35/B Bomb Fuze were modified, where necessary, for adaptation in the latter configuration. The modifications performed can be divided into three categories: minimum, modicum, and maximum. The following tabulation summarizes the adaptive work carried out during the course of the FMU-35/B design and development.

Degree of Modifications	Subassembly Modification(s) Made
A. Minimum	1. BFD (Battery Firing Device) - Corrected interference condition between the rotor keys and firing-pin-housing keyways; modified pin locks to prevent jamming; redesigned to allow arming of safing switch at time lanyard is pulled.
	2. Safing Switch - Miniaturized switch; increased threshold; rectified "popping out" of switch mass.

Degree of Modifications	Subassembly Modification(s) Made
	3. Impact Switch - Increased function threshold.
	4. Booster - Increased charge from 15 gm to 45 gm after considerable experimentation.
B. Modicum	Explosive Train - Provided O-ring seal to BFD well to seal fuze assembly; provided mounting space for impact and AD switch; reduced air gap between detonator and booster (increased booster size); changed switching portion of assembly to provide switching functions; increased structural integrity.
C. Maximum	1. Selector Switch - Established new design; reduced number of settings from initial 45 to 35 (plus SAFE setting); provided manual lock; provided O-ring seal; provided printed-circuit plate within selector knob housing assembly.
	2. Anti-Disturbance Switch - Designed and developed new switch; initially designed switch with printed circuit; redesigned switch to contain spur-gear contacts.
	3. Liquid-Ammonia Battery - Designed and developed completely new power source to supply power for 36 hours. Changed components and fundamental designs several times during course of contract to arrive at compatible and workable source.

Degree of Modifications	Subassembly Modification(s) Made
	4. Electronics Package - Designed and developed new electronics package including new time-base oscillator, bimag counter, and decade counter; changed components and counter designs during course of contract to arrive at compatible and workable electronics.

Comprehensive programs of evaluation were carried out by the contractor, the liquid-ammonia-battery subcontractor, and Eglin Air Force Base personnel during the contract period. The programs included

- Development Tests - Environmental and rough handling tests on fuze components; systems tests, compatibility tests, simulated flight tests, environmental tests, and safe-handling tests on fuze assemblies.
- Qualification Tests - Environmental, function, out-of-line safety, flight, ejection-rack, acoustical noise, and safety tests on fuze assemblies.
- Air Force Tests - Flight, sled, and environmental tests on fuze assemblies.
- Development and Qualification Tests on Liquid-Ammonia Batteries

Any failures resulting from the evaluations programs were analyzed and corrective actions taken. Because of evaluation and attendant failure-analysis programs, it was possible to make the corrections necessary for the fabrication of fuze assemblies with a reliability in excess of 0.9 with a 90-percent confidence level.

A value engineering program was conducted during the Phase I period of the FMU-35/B design. In making objective reviews of the various design elements, proposals were accepted for design implementation:

elimination of the stainless steel insert in the contact ring; simplification of the BFD firing pin; fabrication of the contact cylinder by extrusion; and using a decal-type marking for labeling the dial positions.

A two-phase program was conducted to design, fabricate, and qualify an E-Cell timing concept for long-delay, bomb-fuze applications. Phase I was devoted to developing the timing concept. Tests were performed on the timer and its components to prove their ability to operate under the conditions experienced by tactically delivered long-delay bomb fuzes. During Phase II the E-Cell timing concept was combined with the FMU-35/B fuze and qualification tests were performed on the combination.

SECTION III

TECHNICAL DETAILS - DESIGN AND DEVELOPMENT

A. GENERAL

This discussion of the design and developmental events resulting in the end item considers the fuze subassemblies first and concludes with a discussion of the design and development of the fuze assembly from its conceptual status on 17 June 1963 to its terminal status on 1 January 1967. The subassemblies are considered in the order of their involvement in the arming and/or functioning of the fuze: selector switch, battery firing device, liquid ammonia battery, electronics package, impact switch, safing switch, anti-disturbance switch, explosive train, and booster.

B. SELECTOR SWITCH

During the first quarter of the preliminary design, work on the selector switch was concerned with the determination of the circuitry necessary for provision of the required 45 delay settings. Honeywell requested that the number of delay settings be reduced to 35, pointing out that this revision would result in the following advantages:

- Use of a higher-frequency oscillator (8. 34 Hz instead of 2. 33 Hz) would make more space available in the electronic package.
- Elimination of two bimag (binary magnetic) counters would lower unit cost.
- Reduction of the number of delay function times would simplify the selector switch.

On 29 August 1963, Eglin Air Force Base granted permission to conduct such an investigation. It was completed in October and revealed that the advantages could be attained by making the delay-setting reductions and changing the minimum, time-delay increment from 15 minutes to 20 min-

utes. The design of the selector switch was also completed during October. It provided a small, rugged, O-ring-sealed switch that could be manually locked in any one of 35 time-delay settings or in the SAFE position. The manual lock was designed so that the fuze can be installed in the bomb only when the switch is in the locked position; it also relieves the O-ring seal during setting to minimize the effort in setting the switch.

The selector switch assembly (Figure 1) at contract termination consisted of the following subassemblies and components:

- Housing Assembly. This assembly (Figure 2) contains the printed-circuit contact plate, and provides the mounting structure for the electronic assembly.
- Cover Assembly. This assembly (Figure 2) contains the wiper plate, the contact wiper for completing the switch circuits, the setting knob, and the slider. The slider provides positive switch positioning by engaging a notch in the housing rim. It also actuates the sealing mechanism.
- Retainer Ring and O-Ring Seal. These components (Figure 3) form the sealing mechanism.

C. BATTERY FIRING DEVICE

Throughout development of both the FMU-35/B and FMU-26/B fuzes, the BFD (battery firing device) designed for the FMU-26/B was also designated for use with the FMU-35/B. The initial design was used successfully with the prototype (Phase I) fuzes and with the early fabrications of Phase II fuzes. However, in October 1964 a series of function tests was conducted and one fuze failed to arm because of an interference between the rotor keys and the firing-pin-housing keyways of the BFD, a condition which was corrected by redesigning the pin locks. (Any BFD redesigns in either the FMU-26/B or FMU-35/B programs were adopted in both programs.) Figure 4 shows the early design.

In July and August 1964, the safing switch function was modified to reduce

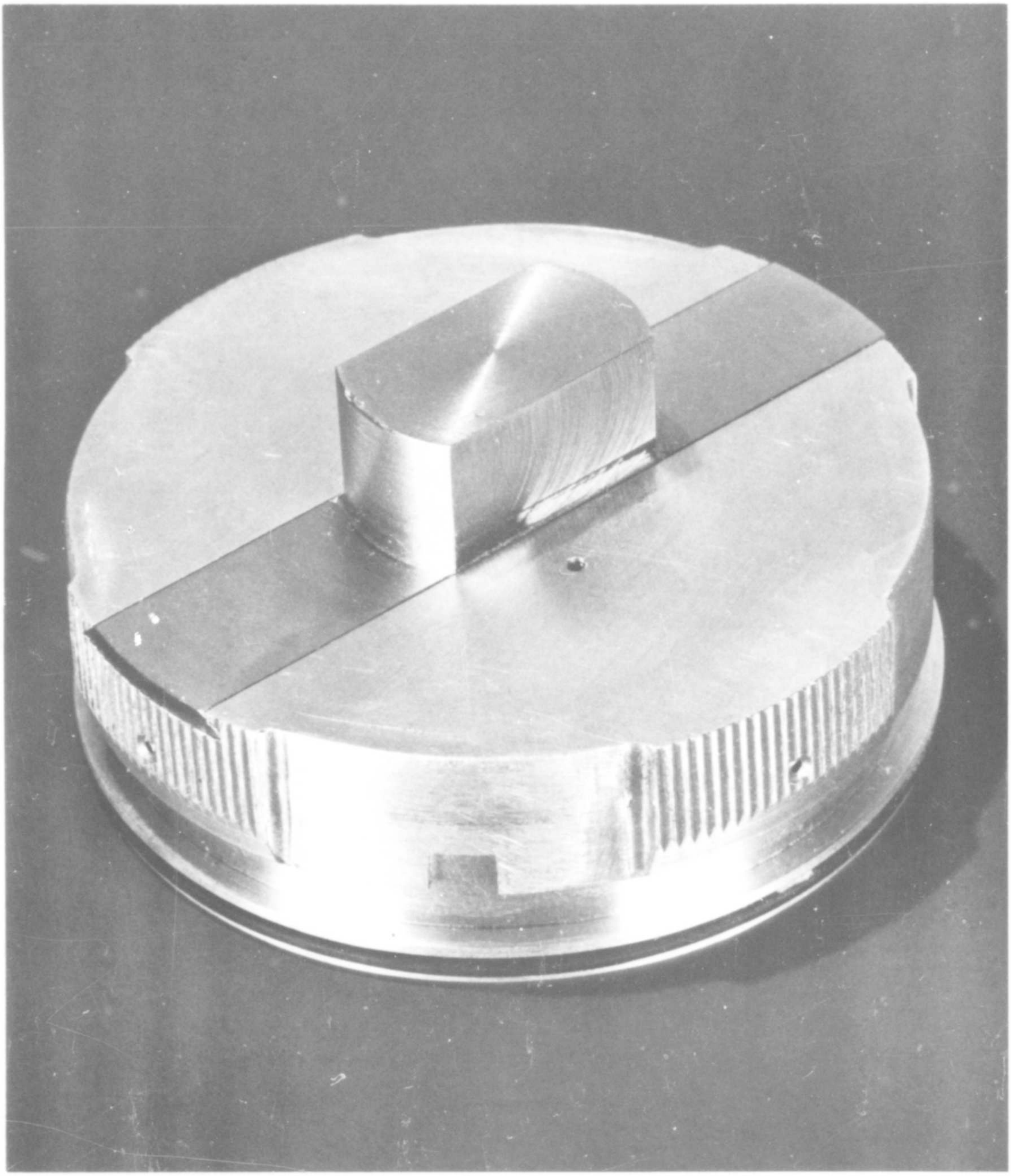

Figure 1. Selector Switch Assembly

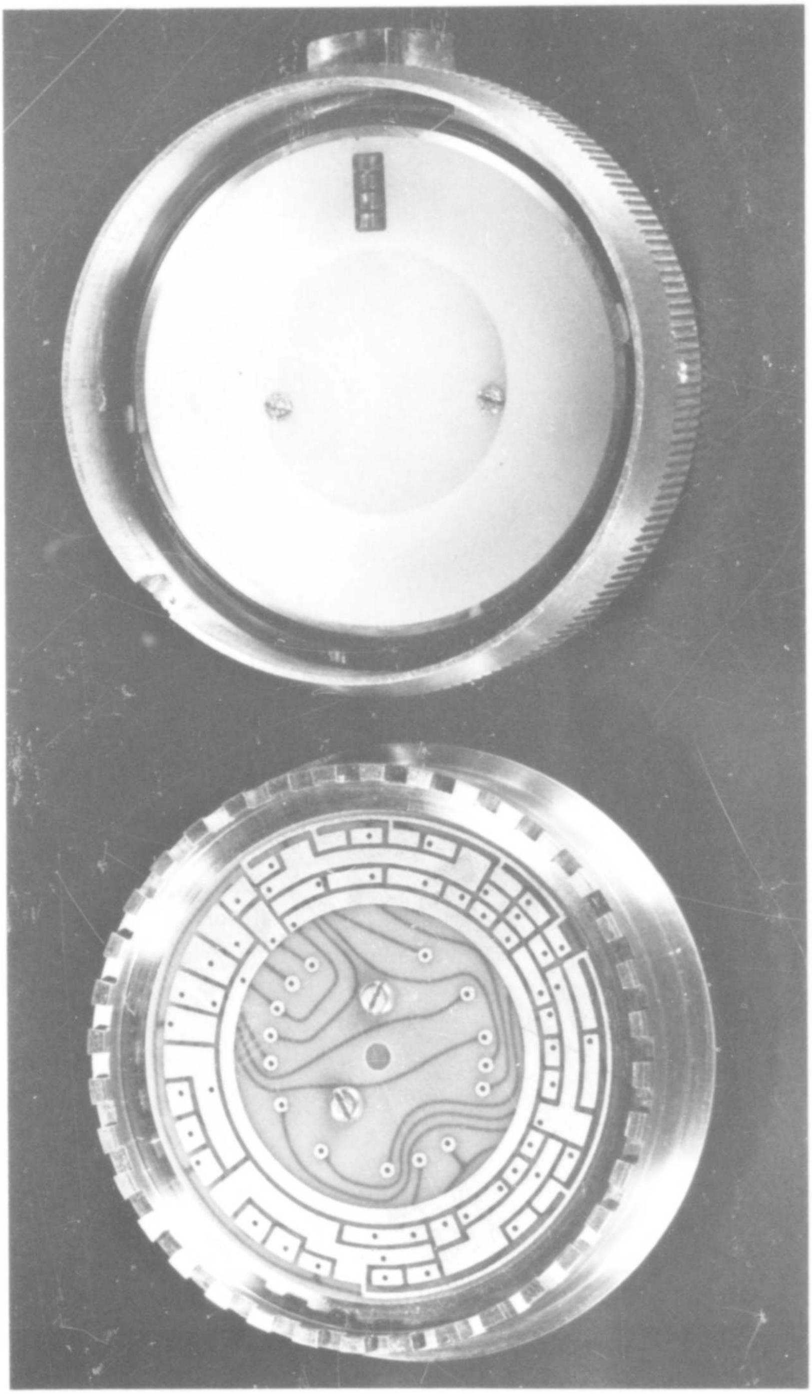

Figure 2. Selector Switch Housing (A) and Cover Assembly (B)

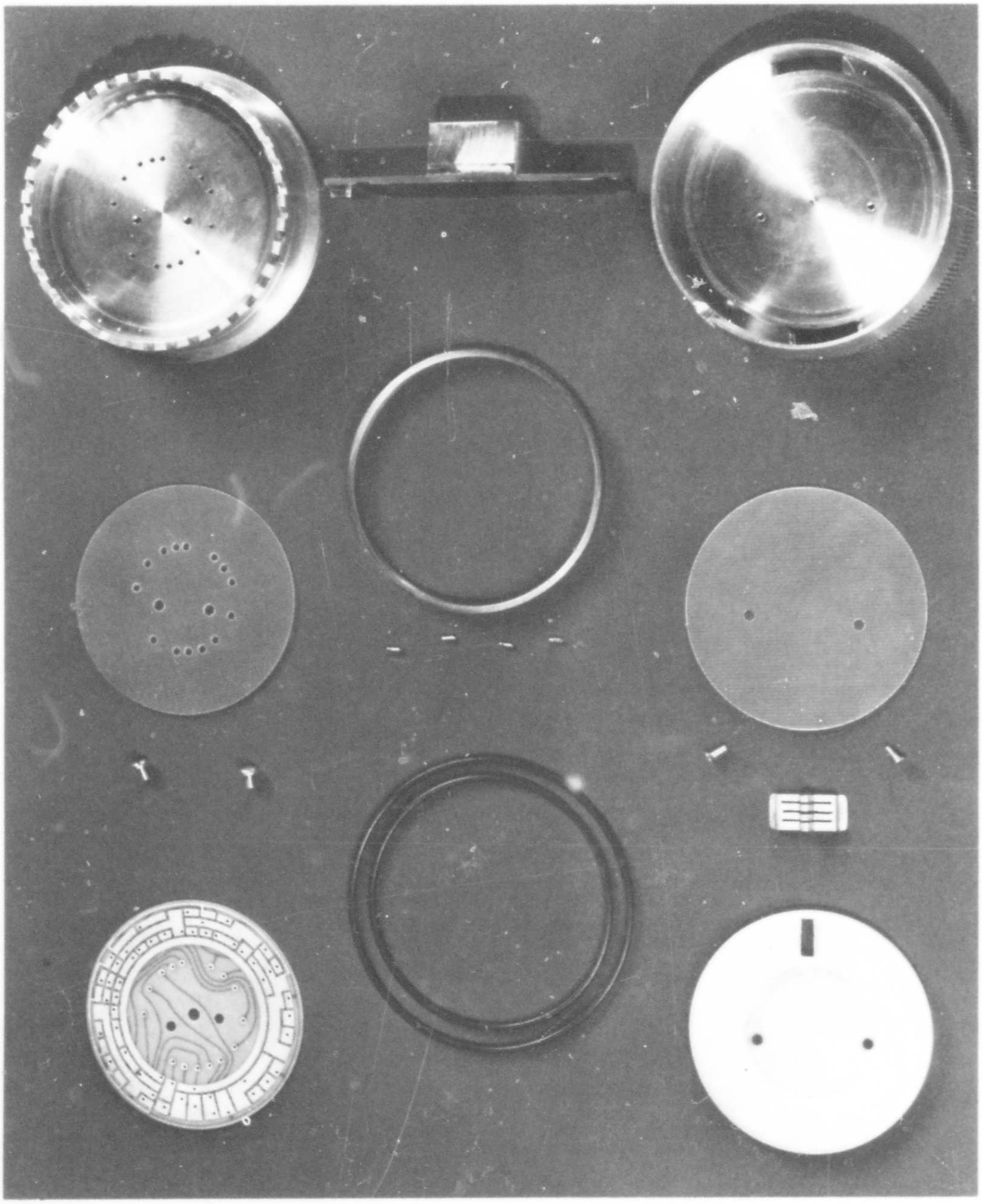

Figure 3. Selector Switch Components

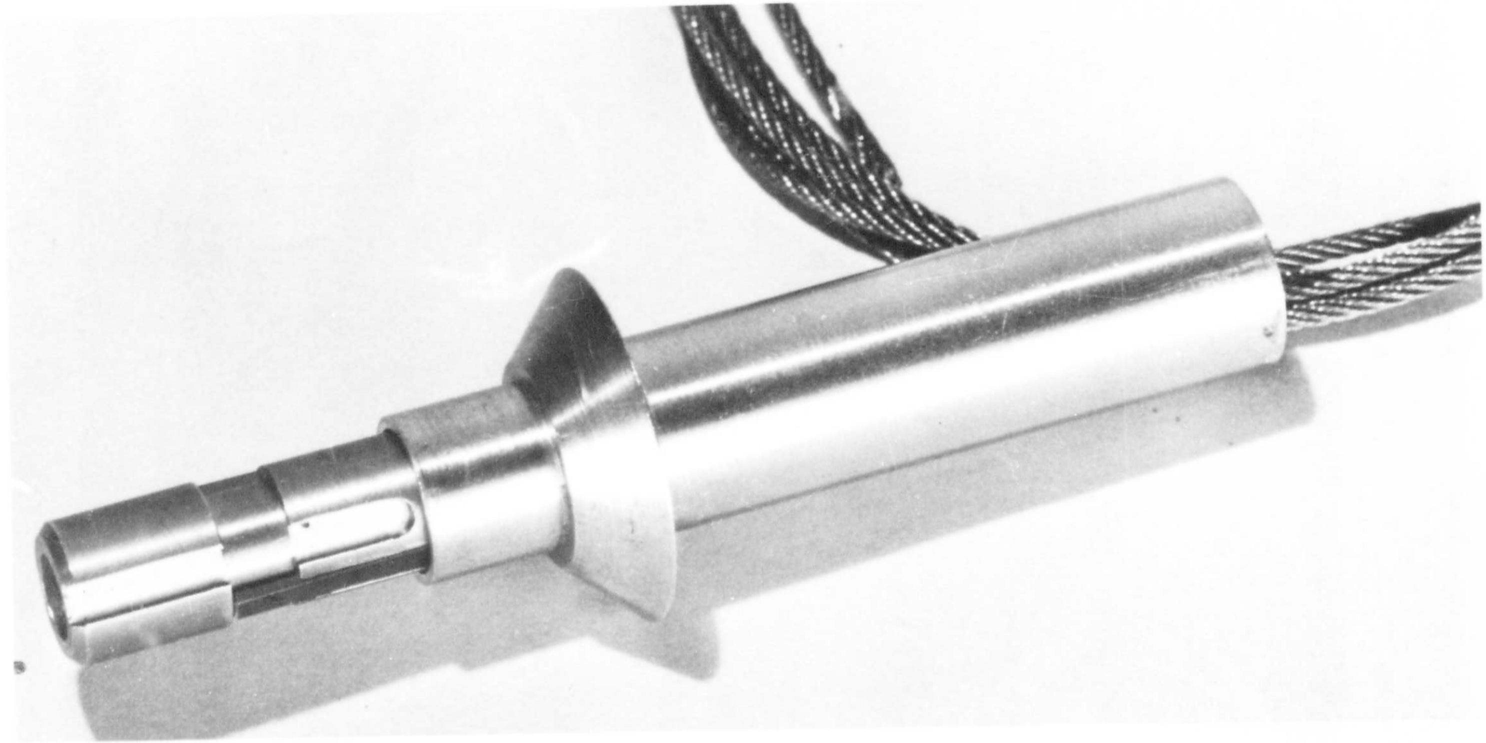

Figure 4. Early Design of Battery Firing Device

the possibility of inadvertent function during handling. The principal effort (August 1964) was the redesign of the BFD to allow it to arm the safing switch when the lanyard is pulled. The redesign of the battery firing device was incorporated in the design package in October. Figure 5 shows the BFD in its redesigned and final form.

The BFD consists of a lanyard cable and a battery initiator. The lanyard cable provides the mechanical linkage between the battery initiator and the aircraft arming solenoid. When actuated, the arming solenoid holds the arming ring through which the lanyard cable is looped. This causes the lanyard cable to be pulled out of the battery initiator to trigger the firing pin. The firing pin impacts the percussion cap of the liquid ammonia battery to activate the battery.

A BFD failure during a flight test in August 1965 prompted the following test program to be undertaken:

(1) The static pull force required to operate a sample of 34 BFD's was determined.

(2) The 34 BFD's (item 1), above, were rebuilt and tested on the Eglin ejection-rack test facilities to provide correlation between the static pull force and BFD function under conditions of forced bomb ejection.

The results were:

Static Pull Force [a] (lb)	Number Tested	Number of Ejection Test Failures
21-25	4	0
26-30	10	1
31-35	10	1
Over 36	10	6

[a]These figures would have been increased by a factor of two if they had been determined under actual bomb installation conditions.

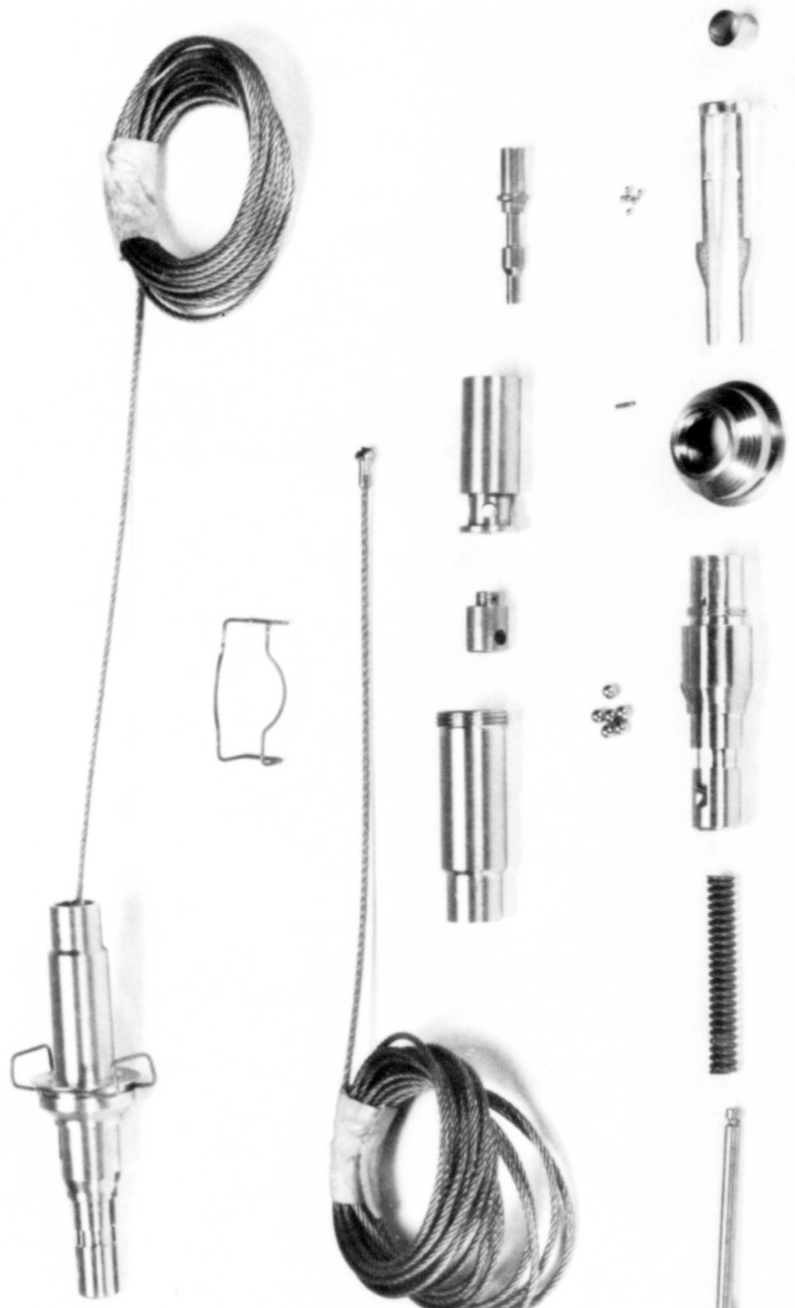

Figure 5. Final Design of Battery Firing Device

The ejection tests bore out the expected high failure rate in the over 36-pound pull group. They also revealed failures in the 31-35 and 26-30 pound pull groups, indicating a failure mode that was not directly related to the static pull force.

Eight fuzes in which BFD's with static pull forces in the 16-20 pound range were employed were flight tested in September 1965. Two of the BFD's failed to function. Analysis revealed that the failures were due to the balls jamming the pin lock under flight-test conditions. The balls prevent the pin locks from moving, except when the lanyard is pulled.

Also, the lanyard-cable-fitting-shank diameter exceeded print requirements in some cases. This condition was not sufficient to cause BFD failure, but could result in increased pull forces.

The 34 devices previously tested on the ejection rack were rebuilt (a) with modified pin locks to prevent jamming, and (b) with lanyards selected for proper diameter. After determining the static pull force of the units, ejection-rack tests were repeated on 32 of them, reserving the remainder for FMU-26/B flight tests. The maximum static pull force on any of the devices was 32 pounds; all 32 devices passed the tests. Two devices flown in FMU-26/B fuzes passed the flight test.

During the first week in December 1965, modification of the method of attaching the BFD to the fuze-well nut was considered in the FMU-26/B fuze development program. One of several different designs studied was selected for fabrication and testing the latter part of December. The retaining clip, shown in final form in Figure 5, was fabricated of corrosion-resisting, spring-tempered wire. The initial configuration underwent four minor changes in March, April, and June 1966 as a result of test findings. The final configuration proved satisfactory in holding the BFD to the fuze-well nut and preventing the BFD from tipping prior to fuze installation.

D. BATTERY

1. Battery Requirements

The thermal battery used in the FMU-26/B fuze to power the arming and function circuitry could not be used in the FMU-35/B fuze because its life is approximately 2 minutes. The battery life requirement for the FMU-35/B is that power be available for at least 36 hours.

As prescribed in the preliminary battery requirements for the FMU-35/B fuze: "The battery shall:

- Be of the reserve primary type.
- Be initiated by impact of a percussion cap; the fuze assembly shall supply the impact by means of a firing pin.
- Supply, when initiated, 9.0 ± 1.8 vdc from 0.5 second to 36 hours after initiation at a continuous current drain of 12.0 ma.
- Supply two current pulses for 5 ms any time during the 36 hours.
- Be enclosed in a package 2.5 inches long by 2.6 inches in diameter (exclusive of terminals).
- Be hermetically sealed iaw MIL-STD-108.
- Withstand the rough-handling requirements of MIL-STD-300, 301, 302, 303, 358, and MIL-E-5272C prior to initiation.
- Withstand, while operating, a shock of 3000 g for 1.0 ms in any axis.
- Withstand storage temperatures of -65°F to $+160^\circ$F, and be capable of meeting the operational requirements while conditioned within these temperature extremes.
- Have a storage life of 10 years.
- Operate in any position at pressures from 1 to 32 inches of Hg absolute.
- Not require external power for heaters."

2. Liquid-Ammonia Battery

After a survey of the battery industry to locate a power source that would or could be expected to meet the requirements, the liquid-ammonia battery approach was selected. This type of battery was considered to possess the capability to perform well at the lower extreme of the temperature range (-65°F) without an external heater, and would have long-term-storage capabilities and relatively simple construction. The storage capabilities are made possible by containing the energy-producing materials separately before usage.

Livingston Electronic Corporation, Montgomeryville, Pennsylvania, a subsidiary of the G. H. Corson Company, proposed to develop a liquid ammonia battery to meet the system criteria. Livingston submitted a proposal of such a power source, and described the concept (Figure 6) briefly as follows:

> "The cell structure will consist of five individual cells approximately 1/4-inch thick and have a magnesium anode at the center and a molded cathode at the periphery. The cells will be stacked at the terminal end of the battery and each will produce approximately 1. 95 vdc, maximum. Cells of this type of construction have yielded up to 70 hours of operation while supplying 12 milliamperes at -65°F. The wafer-type construction was chosen primarily because it possesses high-shock-resistant qualities and ability in meeting packaging requirements.
>
> "The reservoir will be a collapsible metal chamber which contains the liquid ammonia before activation.
>
> "A third major part of the battery will be an initiation system composed of a standard percussion cap and a gas generator. When activated, the percussion cap will ignite a gas-generating pellet which collapses the chamber. Movement of the chamber toward the terminal end results in penetration of the bulkhead wall by the lance. This provision of a port will allow the liquid ammonia to be forced into the manifold and then into the individual cells to mix with other electrolyte constituents. Battery action will provide electrical energy for a minimum of 36 hours."

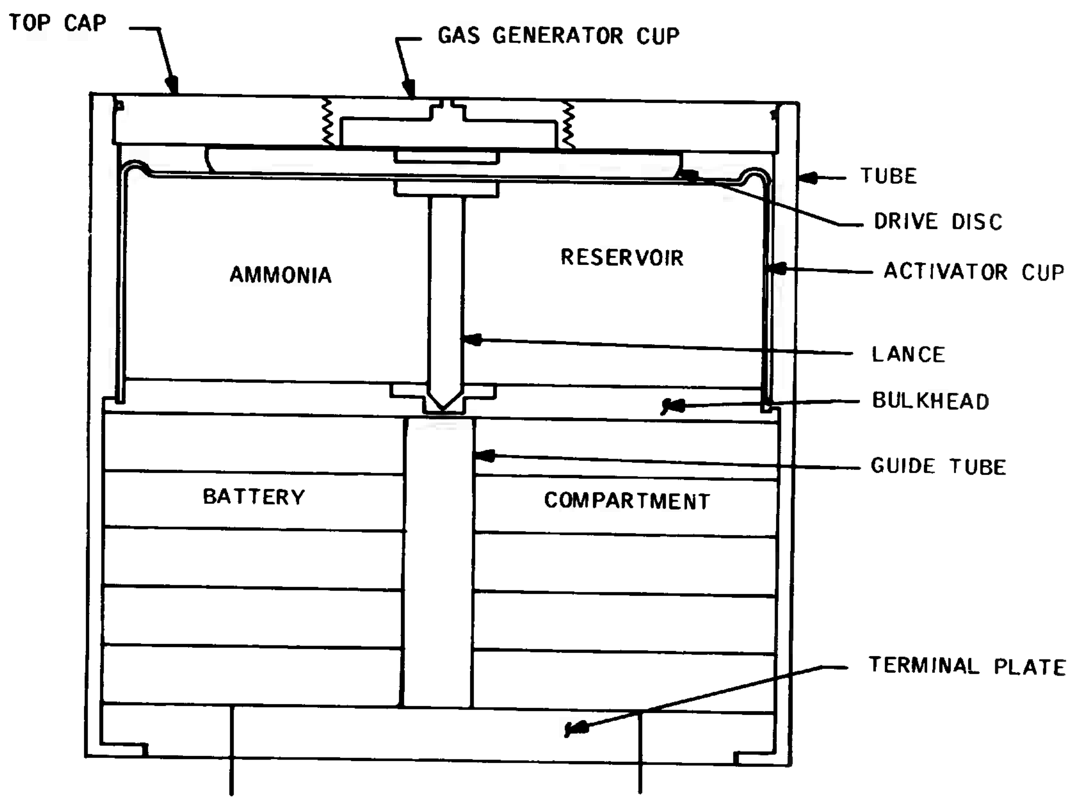

Figure 6. Subcontractor's Concept of Liquid-Ammonia Battery

A subcontract was negotiated and Subcontract No. 127800 was let in June 1963 for the design and development of a liquid-ammonia battery. The subcontractor began work immediately and submitted his first progress report to the contractor in July.

3. Design and Development

Initial battery-design efforts by the subcontractor were concerned with cells, manifold and distribution systems, ammonia reservoir and lance, and gas generator. The following paragraphs chronologically describe the design and developmental work accomplished.

a. Battery-Cell Design. — During July, August, and September 1963, effort was expended in determining the cathode configuration and cell arrangement. Results of tests conducted on cells using cathodes that were fabricated by molding and by pressing indicated that the pressed cathodes were superior. Washer and button-type cathodes were also compared, considering both life and current-density parameters.

Life tests conducted on individual cells, using button-type cathodes containing a mixture of metanitrobenzene, carbon, and potassium sulphate, were consistent and indicated an average cell life of 50 hours. This cell life was considered to be adequate for the margin of safety required to offset intercell leakage when the cells are connected in battery configuration. Development work on cathode materials (electrolyte solute materials) revealed that ball-mill mixing produced good results.

Five-cell batteries in the first months of the contract consisted of outer-ring cathodes, center-ring anodes, and ammonia manifolding. These batteries (Figure 7) fell short of requirements, particularly in the area of battery life. Intercell leakage (up to 19 ma) seemed to be the dominant factor. In spite of incorporating insulated header plates and ion-exchange

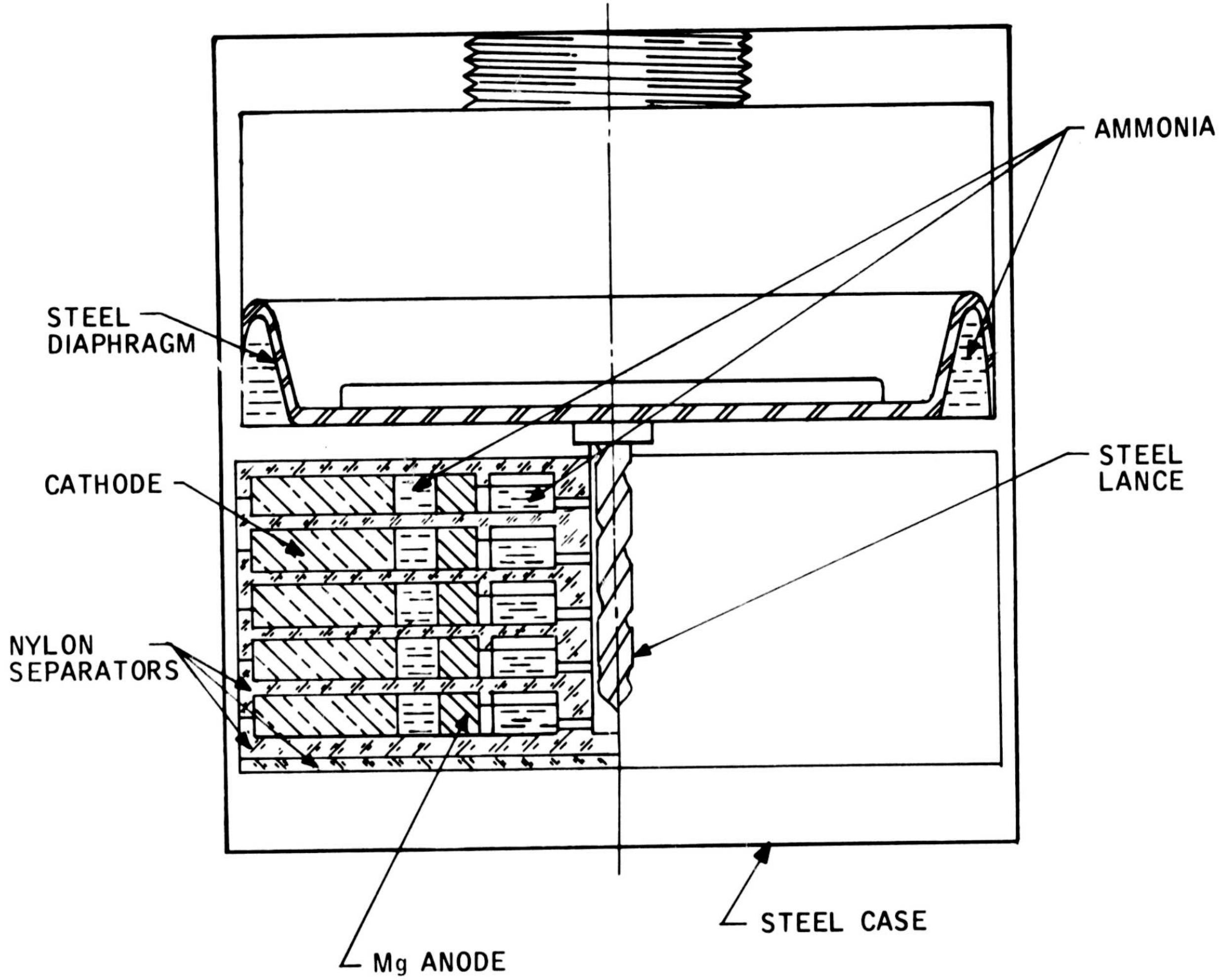

Figure 7. Early Development Design of Liquid-Ammonia Battery

membranes between the cell anodes and cathodes, short battery-life yields of approximately 12 hours were experienced. These yields were consistent, whereas earlier configurations without the insulation materials gave highly unpredictable yields ranging from minutes to 20 hours (lap-joint cell configuration).

From November 1963 through March 1964, efforts were concentrated on improving battery life by experimentation with intercellular insulation, anode structure, cathode structure, cup structure, case insulation, cathode mix/electrolyte volume ratio, addition of silica gel to cathode mix, and cathector materials. Battery life extension, however, continued to be a problem. In December 1963, the contractor and the subcontractor began investigating the possibility of using a single-cell battery with a converter to provide the required power. The contractor had a small solid-state converter available for testing a single-cell battery. Tests conducted the following month were quite successful, particularly with respect to battery life (57 hours) at the higher temperature extreme; however, results were not satisfactory at the lower extreme. Further testing in February 1964 showed that battery life at both room and low temperatures would have to be improved.

At a meeting with subcontractor personnel in April 1964, it was decided that all effort would be directed toward optimizing the multi-cell, "flat pack" design then being used by the subcontractor on a shorter-life battery application. The design had advantages in activation time, size, simplicity, and ruggedness.

Testing of this design (Figure 8) began immediately. So improved was the performance of this cell configuration during April 1964 fabrication and testing, completion of Phase I and initiation of Phase II took place the first week in May.

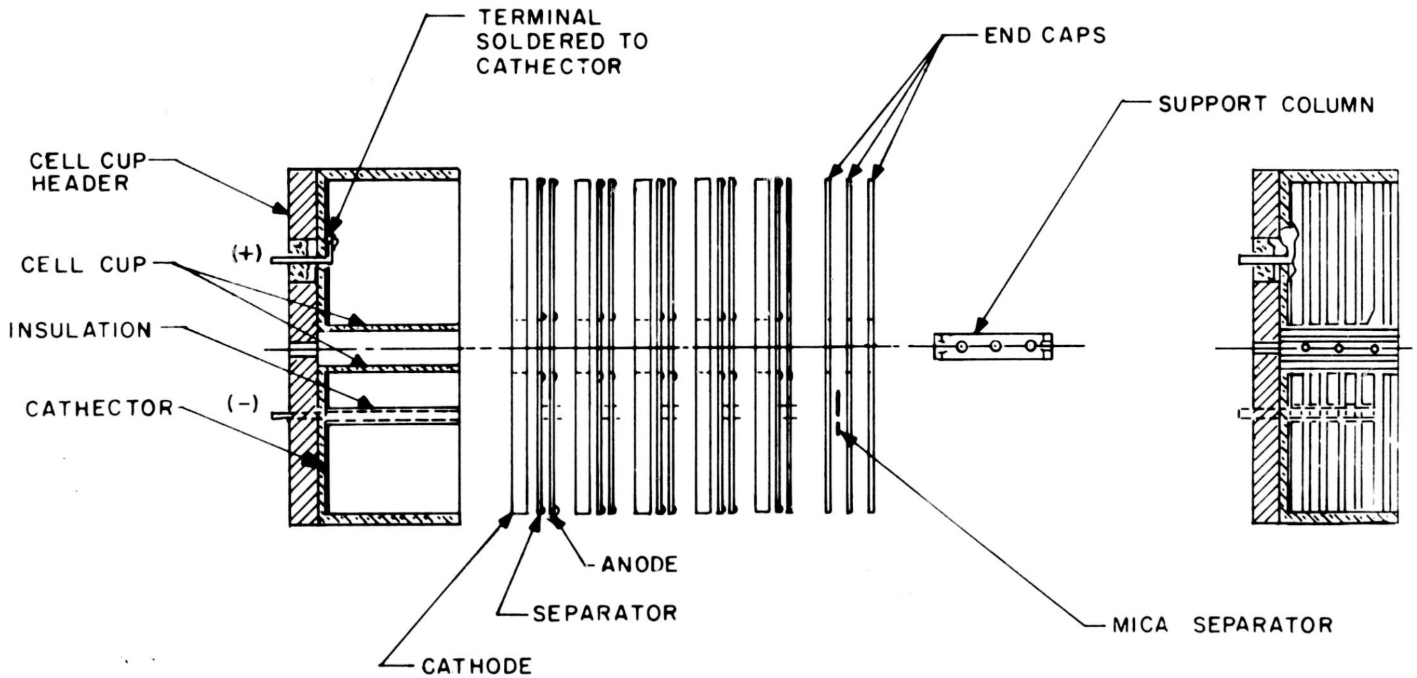

Figure 8. Liquid-Ammonia Battery Cell Stack

The successful results with the "flat pack" cell stack design included battery life in excess of 40 hours in the large majority of 25 test runs. The activation times were also repeatable.

As Phase II work progressed, problems arose at the high temperature extreme, +160°F. A number of test samples exhibited battery life of only 7 to 12 hours. In September 1964, a new thicker bimetal anode (silver/magnesium) was used with an improved cathode mix; and in October and November testing sequences, battery-life requirements for the entire temperature range (-65°F to +160°F) had again been met. The battery design was then modified to reduce the overall height to 2.036 inches. This reduced height was required to allow installation of a larger booster. The batteries fabricated in September, October, and November 1964 were of the 2-inch-high configuration.

Environmental tests were performed on Phase II batteries in February 1965. A number of activation failures, and short battery-life failures were experienced during this testing; however, none of the failures was attributed to cell failure. They were considered to have been the result of sealing deficiencies in all three major sections of the battery.

Due to these failures, the subcontractor began investigating the feasibility of providing reliable metallic seals in place of the epoxy seals being used. The major concern in using metallic seals was protecting battery components from heat generated during sealing. To prevent a heating problem, electron-beam welding was used to provide the required metallic seals. The investigations continued for 6 months until both contractor and subcontractor were assured that repeatable battery performance had been attained. This goal was reached by the middle of August 1965, and the remaining Phase II batteries were fabricated with electron-beamed welded seals.

b. <u>Manifolding and Distribution System.</u> - The manifold and distribution system of the battery functions as the porting system for transferring the ammonia to the cell structure. Within the cell structure, the ammonia mixes with the solvent to form the system electrolyte.

The subcontractor in his proposal to supply an ammonia battery presented the manifold chamber concept shown in Figure 6. In this concept, a cylindrical manifold chamber in the center of the cell structure was to receive the ammonia after the lance pierced the ammonia chamber, and from holes in the manifold and in the insulation cylinder, distribute the ammonia to the layered cell structure. After experimentation with locating the chamber in peripheral areas of the cell structure (Figure 7), the final configuration became basically that of the original concept, but with refinements. Figure 8 shows the support column which doubles as a manifold chamber. Four rows of three holes, spaced 90 degrees apart, are the distribution ports for the ammonia. Figure 9 is a cross-sectional view of an initiated battery in which the lance has pierced the ammonia chamber.

To assist in the ammonia distribution, the inner cylindrical wall of the cell cup has "weep" holes which are aligned with grooves in the cathode discs (Figure 10). The "weep" holes in the cell cup are not necessarily aligned with the four rows of holes in the support column.

c. <u>Ammonia Reservoir and Lance.</u> - The basic material, configuration (Figures 7 and 9), and assembly techniques of the ammonia reservoir and lance were established during the July-September 1963 quarter. Reservoir capacity was increased several times following battery evaluations, and the ammonia fill at production-release time (3 March 1966) was fixed at 16.0/16.4 grams of refrigeration-grade, anhydrous liquid ammonia. After the ammonia fill, a ball seal is used to seal the bulkhead to which the activator cup has been brazed.

KEY:

1. GAS GENERATOR CUP
2. TOP CAP
3. PRIMER CHAMBER
4. IGNITER-GAS GENERATOR CHAMBER
5. ACTIVATOR CUP
6. AMMONIA RESERVOIR (AMMONIA EXPELLER)
7. DRIVE DISC
8. LANCE SUPPORT
9. LANCE
10. BULKHEAD
11. SUPPORT PLATE
12. CATHODE
13. ANODE
14. POLYPROPYLENE CUP
15. TERMINAL PLATE
16. SUPPORT COLUMN
17. TERMINAL

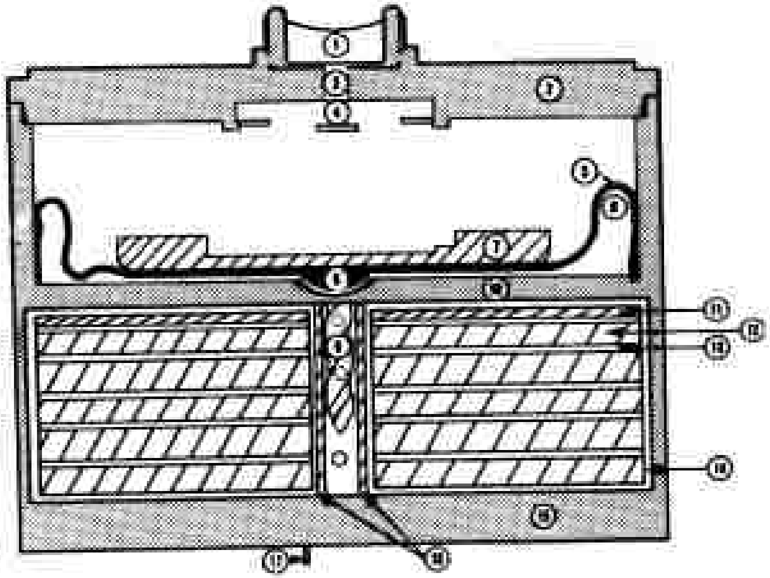

Figure 9. Cross-Sectional View of Initiated Liquid-Ammonia Battery

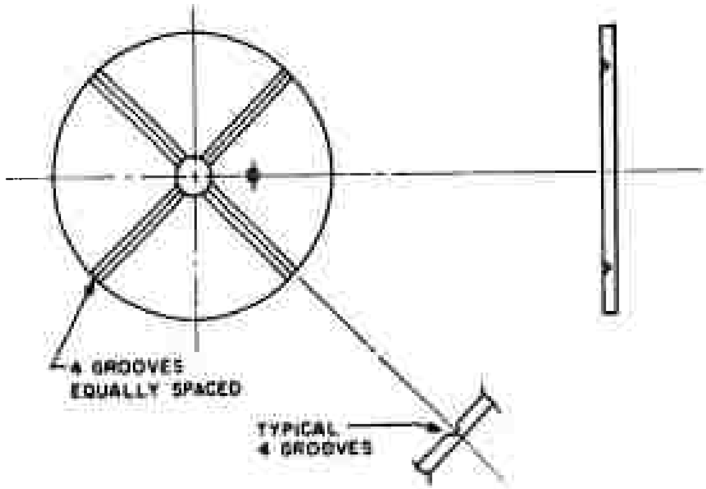

Figure 10. Distribution Grooves in Battery Cathode

A one-eighth inch, high-speed drill is used as the lance to pierce the bulkhead. The lance is peened to a support (A in Figure 11) and the latter is tack-welded to the drive-disc subassembly at the top of the activator cup (B in Figure 11).

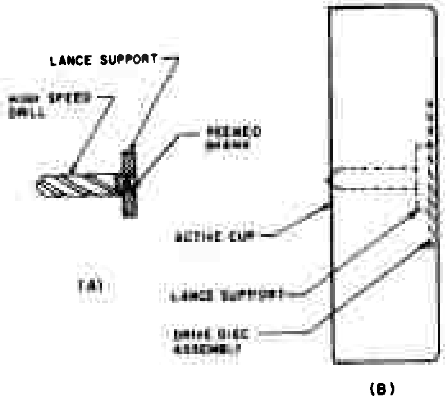

Figure 11. Lance Subassembly (A); Lance-Actuator Cup Subassembly (B)

d. <u>Gas Generator</u> — In the preliminary design of the gas generator, an electrically initiated match was used to fire a booster which ignited a rocket-motor propellant. The propellant output was used to collapse the ammonia reservoir, releasing the ammonia through the manifold to the cells. The electrically initiated match was used for laboratory convenience in establishing time and pressure output curves, and these data were then used to design the percussion-initiated gas generator, a design included in the conceptual design of the battery (Figure 6). In its operation, the released firing pin from the battery firing device fires the percussion-sensitive primer. The latter, in turn, fires the generator propellant, and the pressure buildup from gas-producing propellant collapses the ammonia activating cup.

In August 1964, redesign of the gas generator was found necessary to prevent gas generator pressure leakage around the percussion primer at +160°F. Due to the leakage, the residual pressure was reduced, allowing the reservoir to partially reform, thus relieving the ammonia pressure and reducing battery life. In the redesign, electron-beam welding was successfully used to seal the percussion cap.

In September 1964, five fuzes failed to arm as a result of battery expansion binding the rotor. To minimize the expansion, the gas generator was again revised and additional tests were successful.

Tests were made of various propellant weights and configurations needed to provide sufficient residual pressure without causing case deformation. Terminal data of the charge are: propellant - 0. 750 gram of H9 solid propellant, and circular in shape with an equilateral triangle cutout at the disc center.

Another gas generator problem came to light in October 1965. It was found that the components of the gas generator were not compatible under high-temperature-storage conditions. The problem was solved by inserting a 35-gage Mylar film as shown in Figure 12. Tests run to determine the adequacy of the modification were successful. Figure 13 shows exploded and assembled views of the final configuration of the gas generator subassembly.

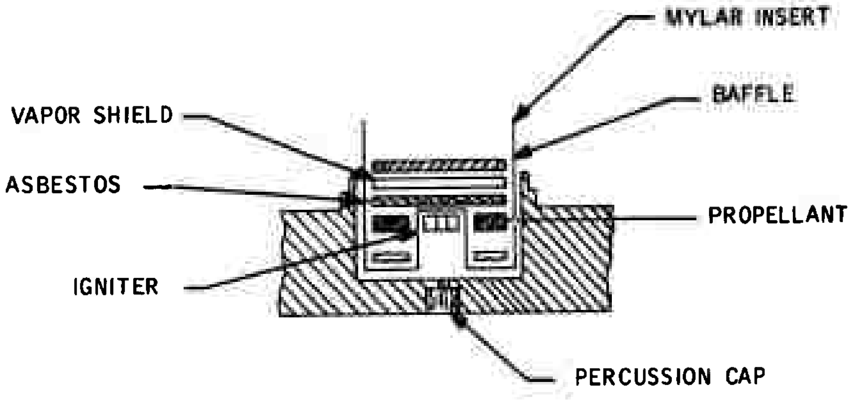

Figure 12. Mylar-Barrier Separator Igniter and Propellant

e. Battery Assembly Considerations. — The previous discussion has been concerned with development of the three subassemblies: gas generator, manifold and distribution system, and cell stack. Development of the battery assembly has already been traced through references to Figures 6, 7, and 9. The latter two views are a cross-sectional drawing and a cross-sectional photograph of assemblies with epoxied seams (rolled and epoxied seams, Figure 9).

(1) Sealing Problems — From contract inception through May 1965, battery life was determined to be inadequate at the upper temperature extreme (+160°F) because of sealing inadequacies. Epoxying, rolling and expoxying, brazing and heliarc welding, and combined epoxying and gasketing were methods employed throughout the period but with successes only at -65°F and room temperature. It was not until the June-October 1965 period, when the subcontractor began employing electron-beam welding, that the contractor indicated battery acceptance for the Phase III fuzes.

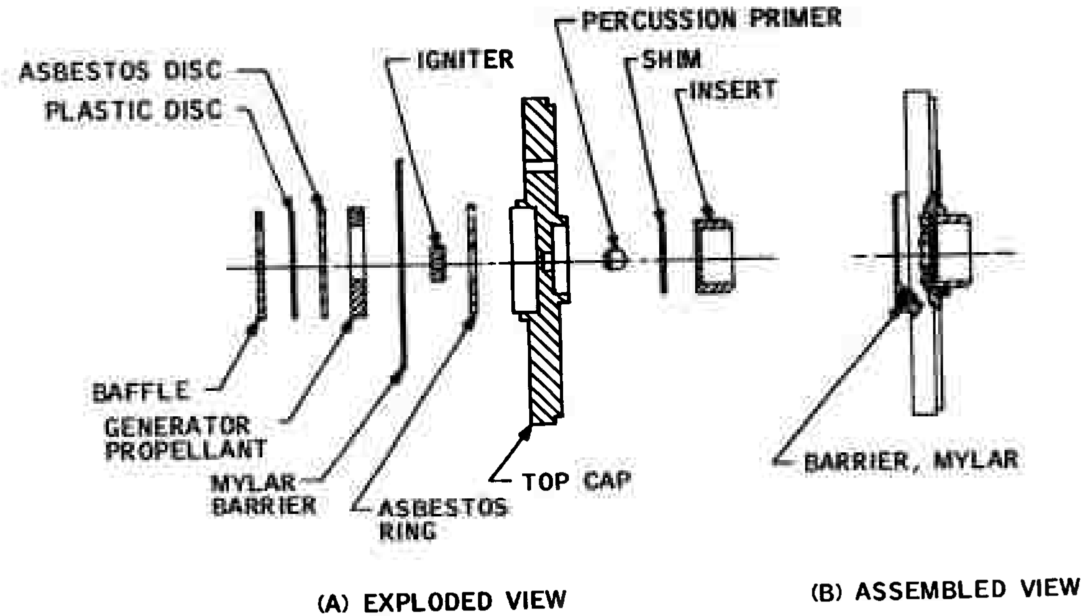

Figure 13. Gas Generator Subassembly

Although there were failures during the environmental testing program that followed, the battery-sealed integrity was not destroyed and it appeared that the failures were caused by the extended periods of storage under high-temperature conditions. It was felt, however, that this welding approach for the terminal ends and percussion-primer ends of the battery provided the means for battery-pressure retention necessary for the required battery life and a measure of time beyond. Braze-sealing techniques were used in all metallic joints other than the welded seams.

(2) Reduced Battery Height — The proposed battery height and the height maintained until early 1964 was 2.5 inches. By April 1964 the height had been reduced to 2.25 inches, but the contractor recommended further reductions to slightly greater than 2 inches to accommodate a larger booster. This was accomplished by refining the cell and ammonia-reservoir subassemblies.

In July 1964, the first 2.0-inch batteries were tested; one battery failed because of pressure leakage at the primer, and the other exhibited a battery life of 52 hours. Satisfactory results were achieved in subsequent testing of 2-inch batteries by increasing the magnesium thickness in the bimetal wafers and changing the cell chemistry.

g. Phase III. — On 16 August 1965, the contractor and subcontractor negotiated to perform two tasks under Phase III of the battery design and development program. The tasks were as follows:

Task I - Incorporate electron-beam-sealing design changes to improve the battery seal.

Task II - Deliver 410 batteries.

Final Battery Configuration — Figures 14 and 15 show the percussion-primer-end view and the terminal-end view, respectively, of the final battery design.

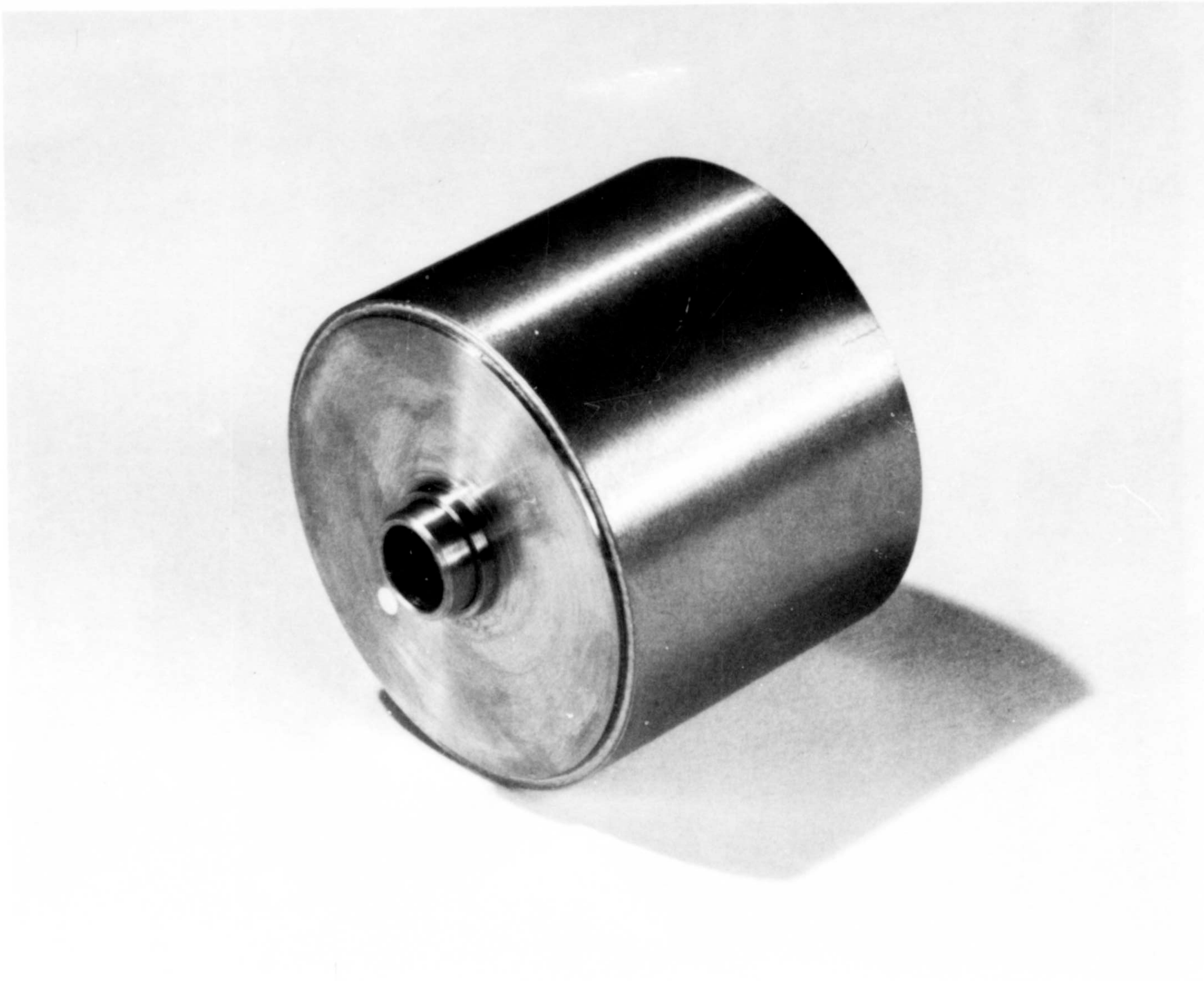

Figure 14. Percussion Primer End of Final Configuration of Liquid-Ammonia Battery

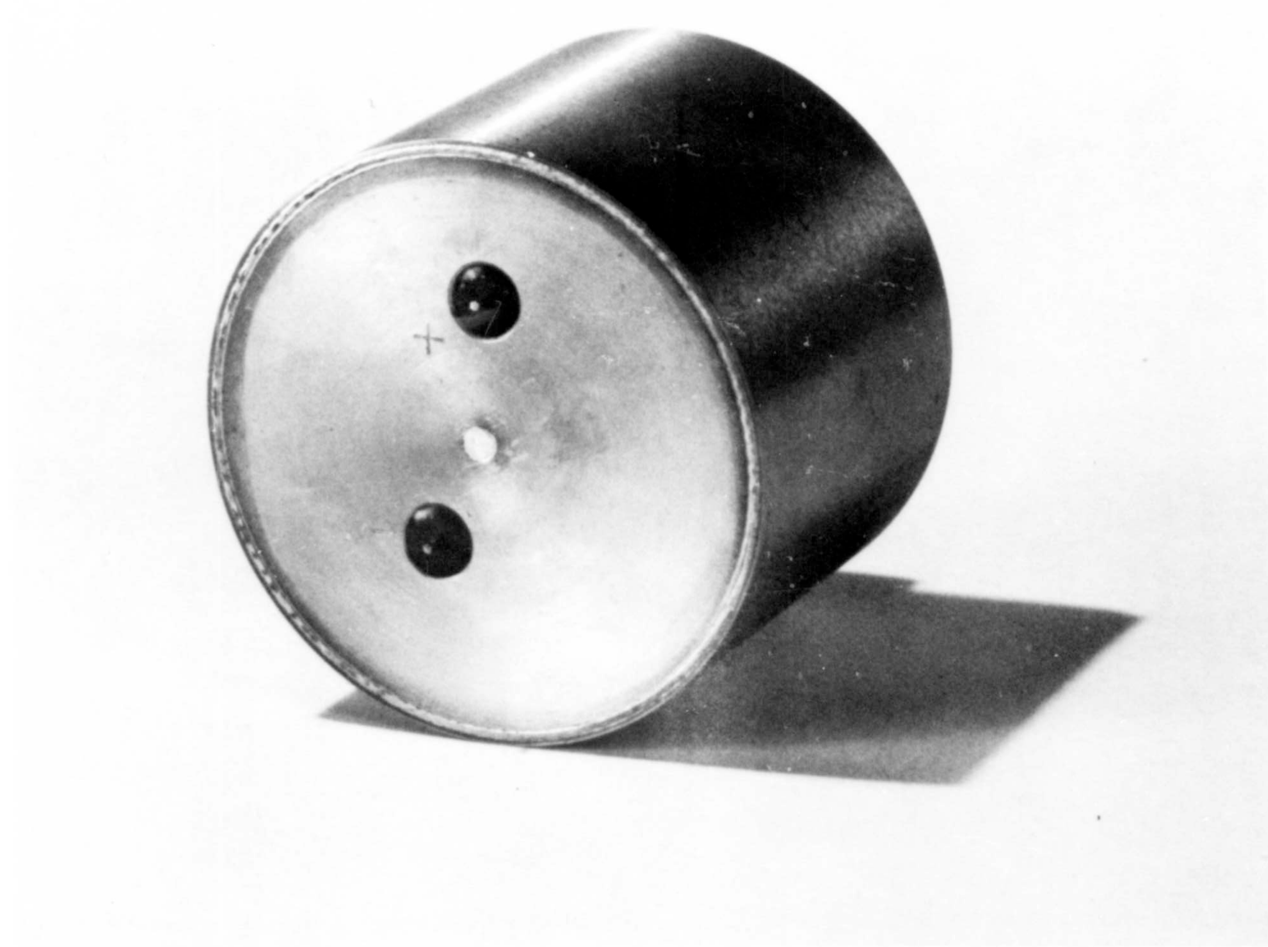

Figure 15. Terminal End of Final Configuration of Liquid-Ammonia Battery

3. Battery Evaluations

Throughout the program, batteries were subjected to acceptance, environmental, and function tests as prescribed by the contract. Tests were conducted at both the subcontractor and contractor facilities from July 1963 through February 1966. The requirements were:

Test Group	Test Requirements
Acceptance Tests	Insulation Resistance ($\geq$ 10 megohms at 25-5 vdc) Cold Voltage ($<$ 0.1 vdc with input impedance of 10 megohms, min.) Activation (7.2 vdc in 750 $\pm$ 700 ms) Post Activation (Life) (12.0 vdc, max., and 7.2 vdc, min. for 36 hr; expansion $\leq$ 0.005 in. along longitudinal axis)
Environmental Tests	Temperature Extremes (-65°F to 160°F) Rough-Handling Requirements: MIL-STD - 300, 303, 301, 307, 302, 358 Aircraft Vibration (MIL-E-52726, para. 4.7, Procedure XII) Shock: 3000 g for 1.0 ms Storage Period: 10 yr. Ambient Atm. Press: 1 to 32 in. Hg Temperature and Humidity: MIL-STD-304.
Function	Initiation by a spherical firing pin and voltage rise to 7.2 vdc in 750 $\pm$ 700 ms.

A summary of the battery-testing program is in Table I.

TABLE I. BATTERY EVALUATION SUMMARY

Test	Time of Tests	Test Results and Comments
I. Acceptance		
A. Life Tests	Dec. '63	Five-cell batteries employing lap-joint cold construction lasted from several minutes to approximately 20 hours. There were no apparent causes of failures.
	Jan. '64	Five-cell batteries employing insulated header plates and ion exchange membranes between all anodes and cathodes yielded life times of approximately 12 hours.
	Feb. '64	Short battery life times (10 to 15 hours) experienced in tests were attributed to excessive inter-cell leakage (up to 19 ma). Employment of valving (ion membranes and O-ring valves) was considered as a method of reducing the leakage.
	Apr. '64	Twenty-six simulated and actual batteries were tested at -65°F and exhibited life times in excess of 40 hours (one, 72 hours), and had consistent activation times.
	May '64	Battery life times were adequate (> 40 hours) at 65°F, but inadequate at room temperature and 160°F.
	June '64	Eight batteries exhibited life times of 9 1/2 to 70 hours, with three in excess of requirements.

TABLE I. BATTERY EVALUATION SUMMARY (continued)

Test	Time of Tests	Test Results and Comments
A. Life Tests (cont'd.)	July '64	One battery of the 2.0-inch length exhibited a life of 52 hours; a second failed to meet the life requirement.
	Aug. '64	Further testing of the 2.0-inch long batteries showed that the design met the life requirements at -65°F and room temperatures but not at 160°F (7-hour life exhibited). Gas generator was redesigned as a remedial action.
	Sept. '64	Battery life of over 40 hours was achieved over the entire range (-65°F to 160°F).
	Sept. '65	One of five batteries with electron-beam welds failed to meet life requirements after a temperature-humidity test.
B. Activation	Dec. '63	Tests on the percussion-cap-initiated gas generator showed excessive activation times (0.9 sec.)
	Feb. '64	Activation time of a single-cell battery with converter was found to be excessive (0.5 to 5.0 sec).
	July '64	After gas generator redesign to minimize 5-cell battery expansion, six batteries were tested and met activation requirements over the temperature range (-65°F to +160°F).
	Aug. '65	After initiation of electron-beam welding, tests showed that activation times were out-of-specification.

TABLE I. BATTERY EVALUATION SUMMARY (continued)

Test	Time of Tests	Test Results and Comments
B. Activation (cont'd.)	Oct. '65	A battery tested at +160°F failed to initiate. It was theorized, and later substantiated, that the extended period of storage at high temperature caused the failure.
	Dec. '65 & Jan. '66	In acceptance tests of Lot 3 and 4 batteries for Phase III fuzes, activation times were exceeded (0.124 to 0.470 sec instead of 0.185 to 0.415 sec). Since the range seemed to be the gas-generator capability in Lots 5 and 6 also, the deviation was accepted.
	Jan. '66	Lots 7, 8, and 9 were accepted with initiation-time deviations.
	Feb. '66	Lots 10, 11, and 12 were accepted with initiation-time deviations. This acceptance completed the Phase III battery order.
II. Environmental Tests		
A. Vibration and Shock	Sept. '63	Two 5-cell stacks were subjected to vibration testing with satisfactory results. The ammonia reservoir and lance assembly was subjected to 3600 g with satisfactory results.
	June '64	Eight batteries were functioned under impact-shock conditions. Batteries and fuzes were found to be compatible under shock environments of up to approximately 20,000 g.

TABLE I. BATTERY EVALUATION SUMMARY (continued)

	Test	Time of Tests	Test Results and Comments
II.	Environmental Tests (cont'd.)		
	B. Temperature Extremes	(Previously listed under Acceptance Tests.)	
	C. Temperature-Humidity	Sept.'65	Two of three batteries subjected to two weeks of the MIL-STD-304 test failed to initiate. It was determined that the failures were not caused by the humidity, but rather by the extended period of high-temperature storage.
		Nov.'65	A lot of ten batteries passed the MIL-STD-304, Temperature-Humidity Test.
	D. A/C Vibration	Sept.'65	Two batteries subjected to aircraft vibration (MIL-E-5272C) functioned properly in all respects.
	E. High-Temperature Storage	(Previously recorded under Acceptance Testing.)	
	F. System Compatibility	Feb.'64	Testing of 5-cell batteries, delivered to the contractor, showed that the cells would function the fuze electronics, but activation and battery-life times were not compatible with the over-all system requirements.
		June'64	Compatibility testing of 20 batteries delivered to the contractor prior to release of Phase II funds showed that they were compatible with the fuze at low and room temperatures and at shock environments up to 20, 000 g.

TABLE I. BATTERY EVALUATION SUMMARY (continued)

Test	Time of Tests	Test Results and Comments
F. System Compatibility (cont'd.)	Sept. '64	After gas-generator modifications, six batteries were tested and showed complete compatability with the fuze.

4. Interim Power Supply

In May 1963, the contractor proposed an interim power supply be employed in fuzes built during the early stages of the liquid-ammonia battery design and development. This power supply was to be composed of eight mercury cells, with the same external configuration as the liquid-ammonia battery. It was initiated by a mechanical switch which itself was actuated by the battery firing device.

NOTE

This type of power supply was not recommended for the final design because its output below -40°F is marginal and high-temperature storage deteriorates capacity below a usable level.

Preliminary design work was completed during the July-September 1963 quarter. On 1 October 1963, the sponsor granted permission to use an external power supply for the Phase I testing. The contractor felt that more data could be obtained if an external supply were used since the interim supply was subject to the environmental limitations mentioned in the note above. As a result, space mockups of the liquid-ammonia batteries were installed in the Phase I fuzes.

E. ELECTRONICS PACKAGE

As stated in the Introduction, the electronics section of the FMU-35/B fuze

required redesign of the similar section in the FMU-26/B fuze because of the longer timing requirements (20 minutes to 36 hours for the FMU-35/B; 2.0 seconds to 21.0 seconds for the FMU-26/B). To provide the time range of 20 minutes to 36 hours, a time-base oscillator (8.33 Hz), a binary magnetic counter, and a decade magnetic counter were designed. Each stage of the decade counter divides the frequency output of the time-base oscillator by ten (10,000 for the four stages) so the period for the decade-counter output is $\frac{1}{8.33/10,000}$ or 1200 seconds (20 minutes). By selecting and grounding various combinations of cores in the bimag (binary magnetic) counter, multiples of this fundamental time period may be selected.

By the end of the July-September 1963 quarter, construction of the counter modules had begun, and temperature tests had been conducted after potting. These initial tests were satisfactory except that low-temperature operation was limited to -40°F. Minor component changes were made to achieve the desired results over the temperature range, -65°F to +165°F at 9 vdc ± 20 percent. Figure 16 is a schematic diagram of the electronics developed for the Phase I fuzes. Figures 17, 18, and 19 show the counter-module placements on the top-board assembly and photographs of the counter modules and the top-board assembly. Figures 20, 21, and 22 show the placement of the remaining electric and electronic circuits on the bottom-board assembly and photographs of those circuits and the bottom-board assembly.

To meet the program schedule, it was necessary to freeze the electronics design in the latter part of 1963, prior to the completion of the breadboard testing. As a result, a number of deficiencies were revealed during the testing of the six Phase I fuzes (December 1963 through February 1964). Bench testing of the Phase I units revealed that the circuitry used for clearing the decade counter at arm (that is, removing any residual count) was insufficient. Breadboard testing showed that by a slight circuit modification and a change in type of diode used, the problem could be corrected.

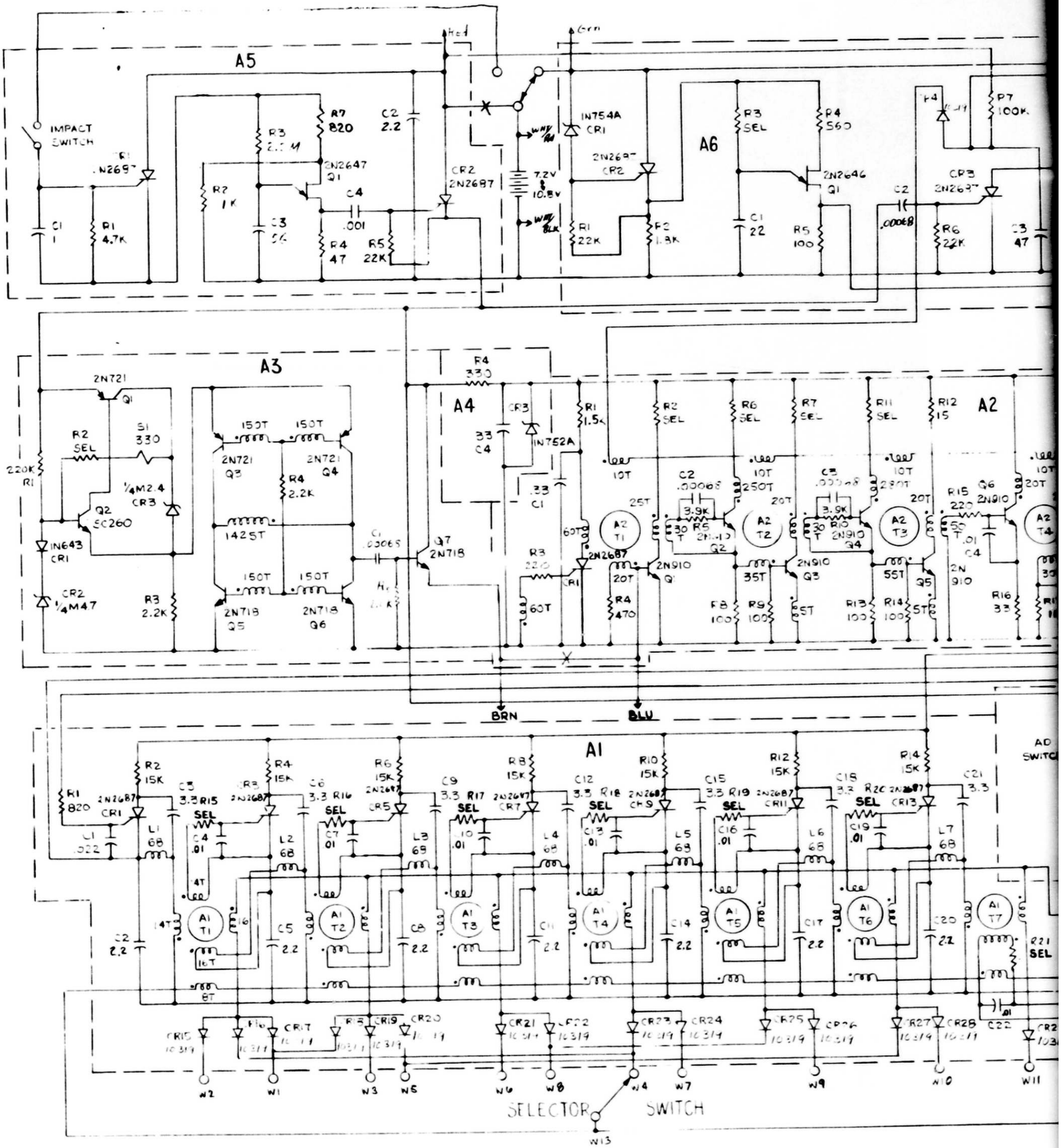

Figure 16. FMU-35/B Electronic System

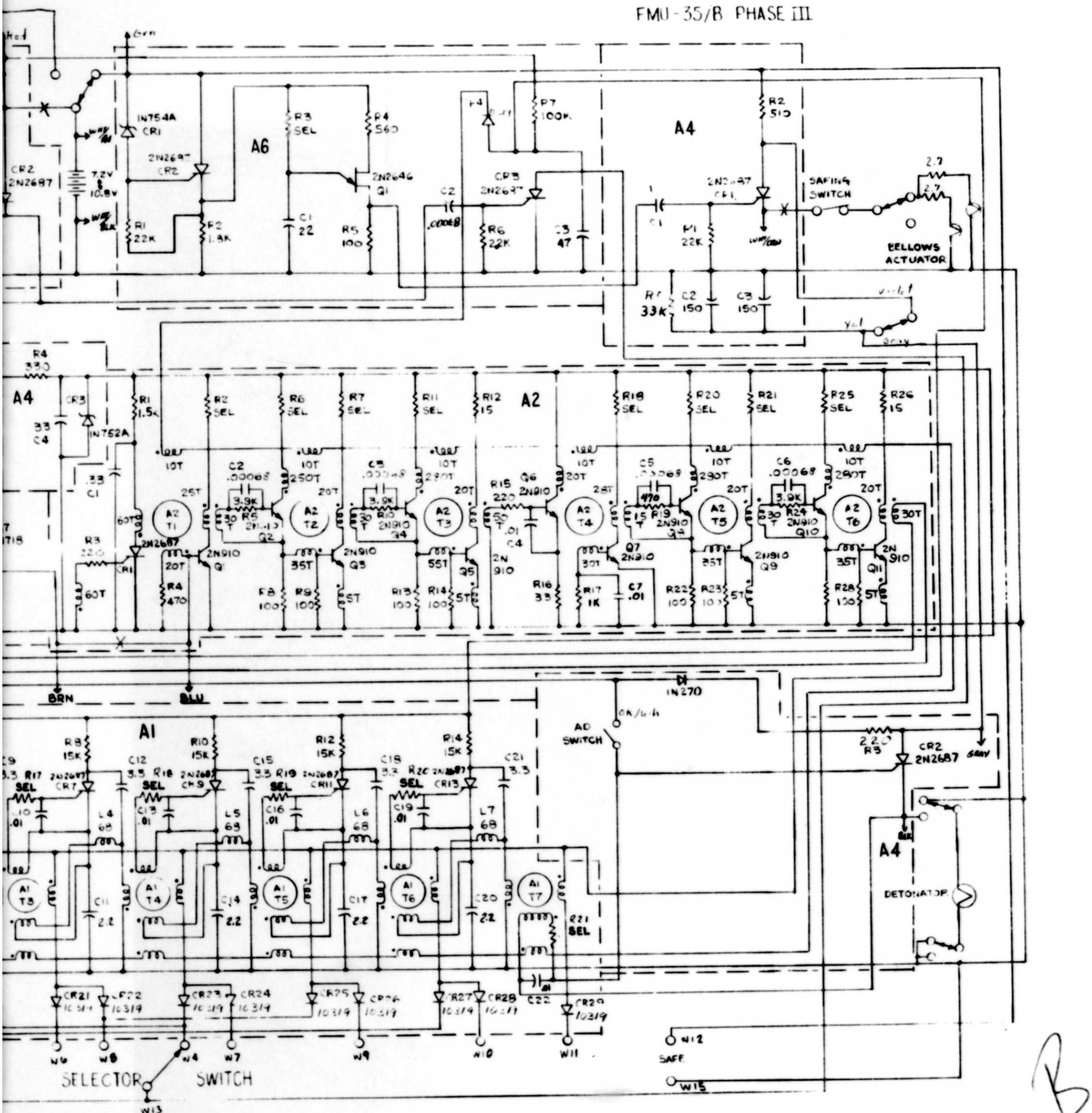

Figure 16. FMU-35/B Electronic System

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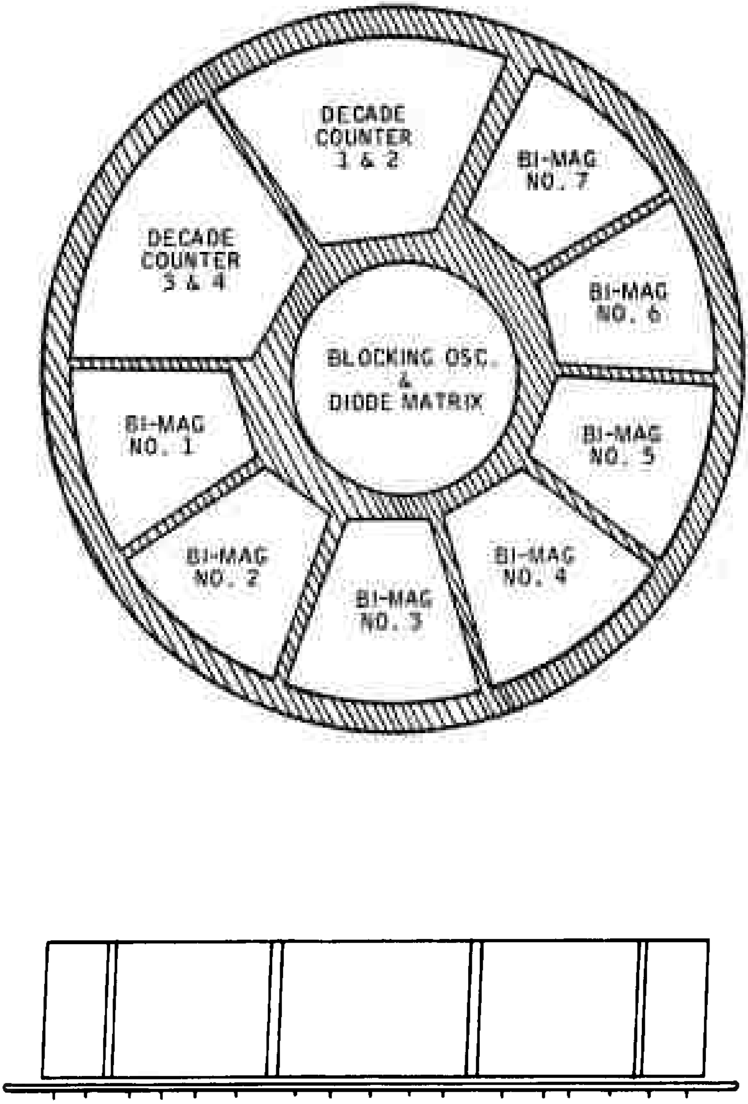

Figure 17. Top-Board Assembly

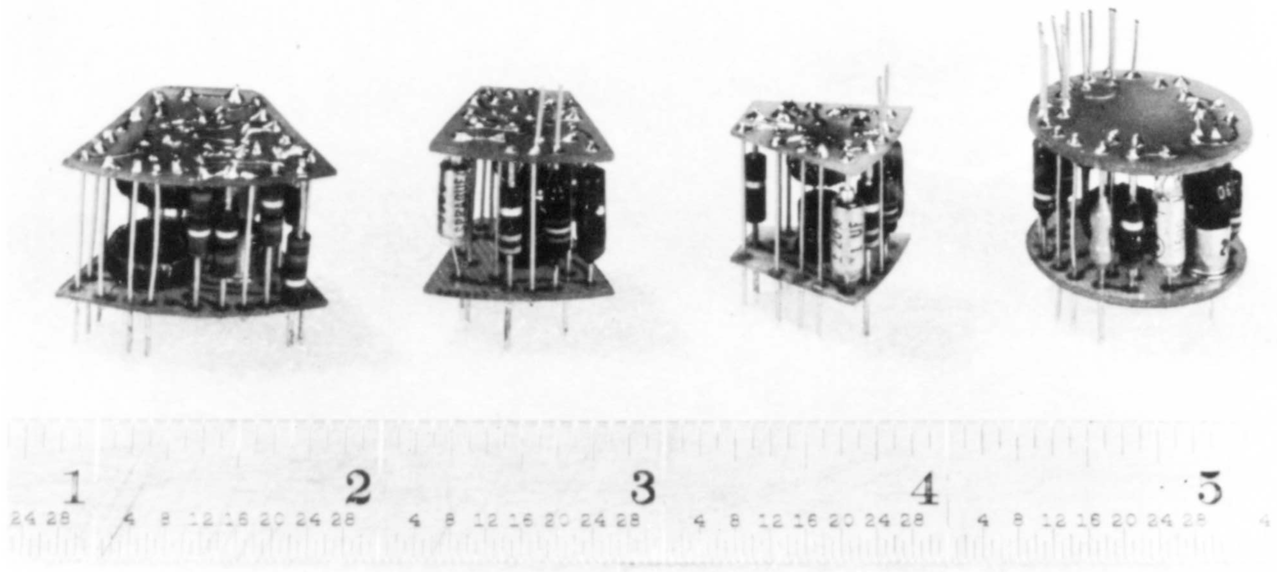

Figure 18. Top-Board Assembly Modules

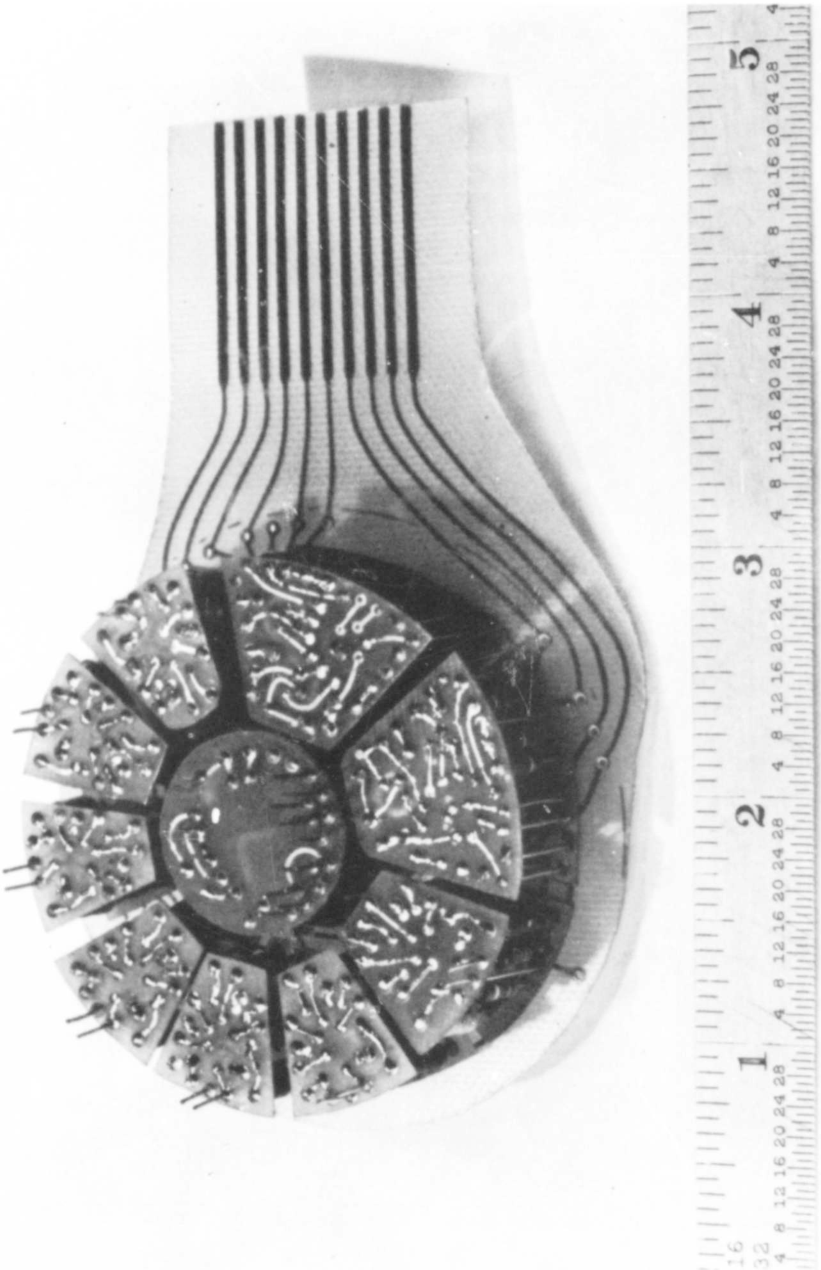

Figure 19. Top-Board Assembly Before Potting

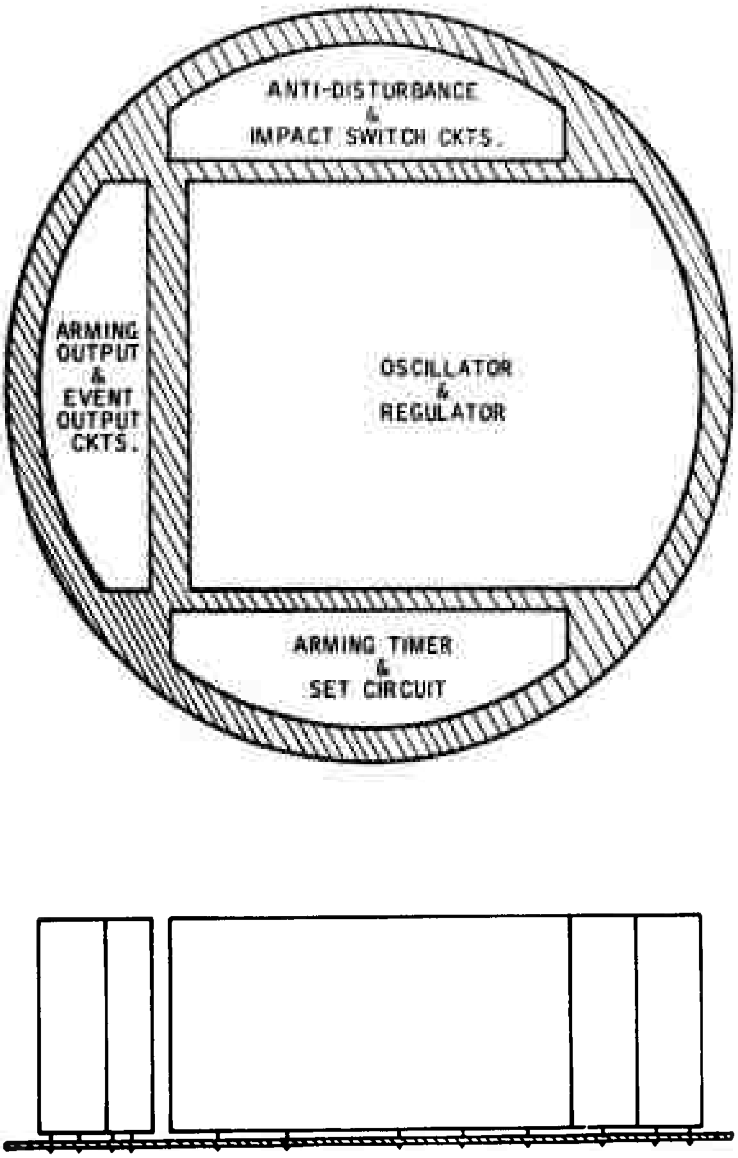

Figure 20. Bottom-Board Assembly

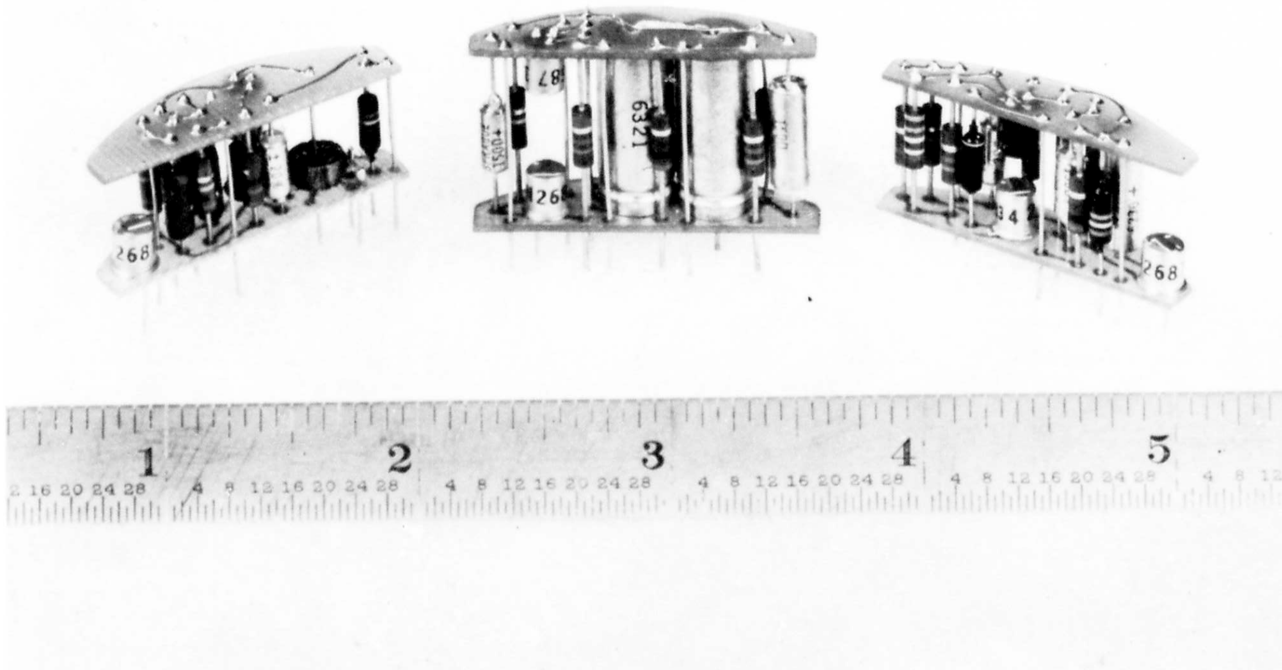

Figure 21. Bottom-Board Assembly Modules

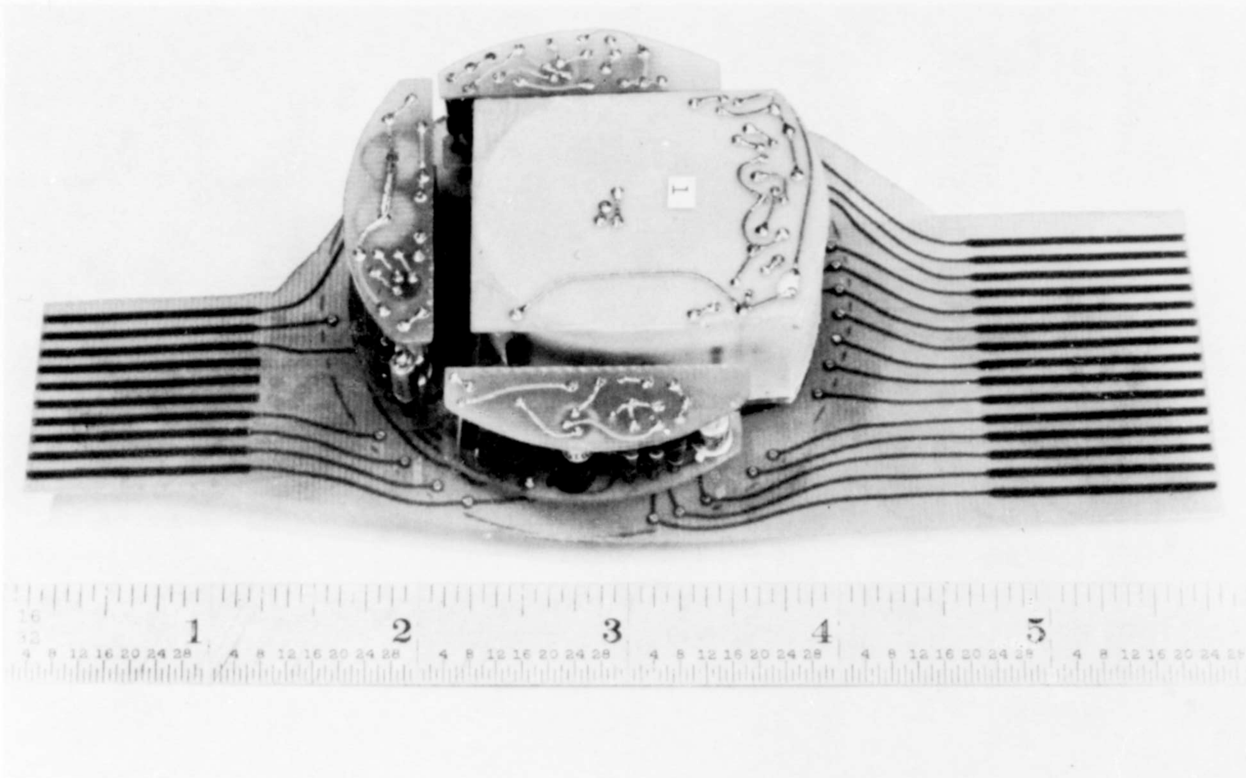

Figure 22. Bottom-Board Assembly Before Potting

These changes were incorporated in the Phase II design.. Testing also revealed decreased fuze accuracies at the temperature extremes. However, this problem was not felt to be serious enough to delay Phase II fabrication and testing.

In September 1964, 18 electronics packages which were scheduled for incorporation in the first of the Phase II fuzes were event tested, and 12 were found to be out of specification in their event times. Six were caused by a shift in decade-counter count, and six by loss of set in the first binary counter or transfer of set in the binary circuits. The problems were eliminated by design changes in the electronic package.

In September 1964, breadboard work was performed on the low-temperature problem in the decade counters. Three problem areas were uncovered and corrected: (1) shorted toroid windings; (2) damaged coupling counters; and (3) changed coupling capacitance over the temperature range. The correction of these deficiencies, however, did not totally resolve the accuracy problem.

Between November 1964 and February 1965, the bimag and decade-counter sections of the electronic assembly were completely redesigned, incorporating the corrective actions taken in the previous months, and also changing the configuration completely from that of the top-board assembly shown in Figures 17-19. Replacing that assembly were the bimag-counter board and the decade-counter board, shown in Figures 23 and 24.

Testing conducted during September 1965 indicated a recurrence of the loss-of-set problem in the counters. To resolve this problem, the fuze circuitry was changed such that the counters were set after impact. This change necessitated incorporation of a post-impact, time delay circuit before setting the counters to allow the bomb to come to rest. This permitted enabling the anti-disturbance circuit at the same time the counters

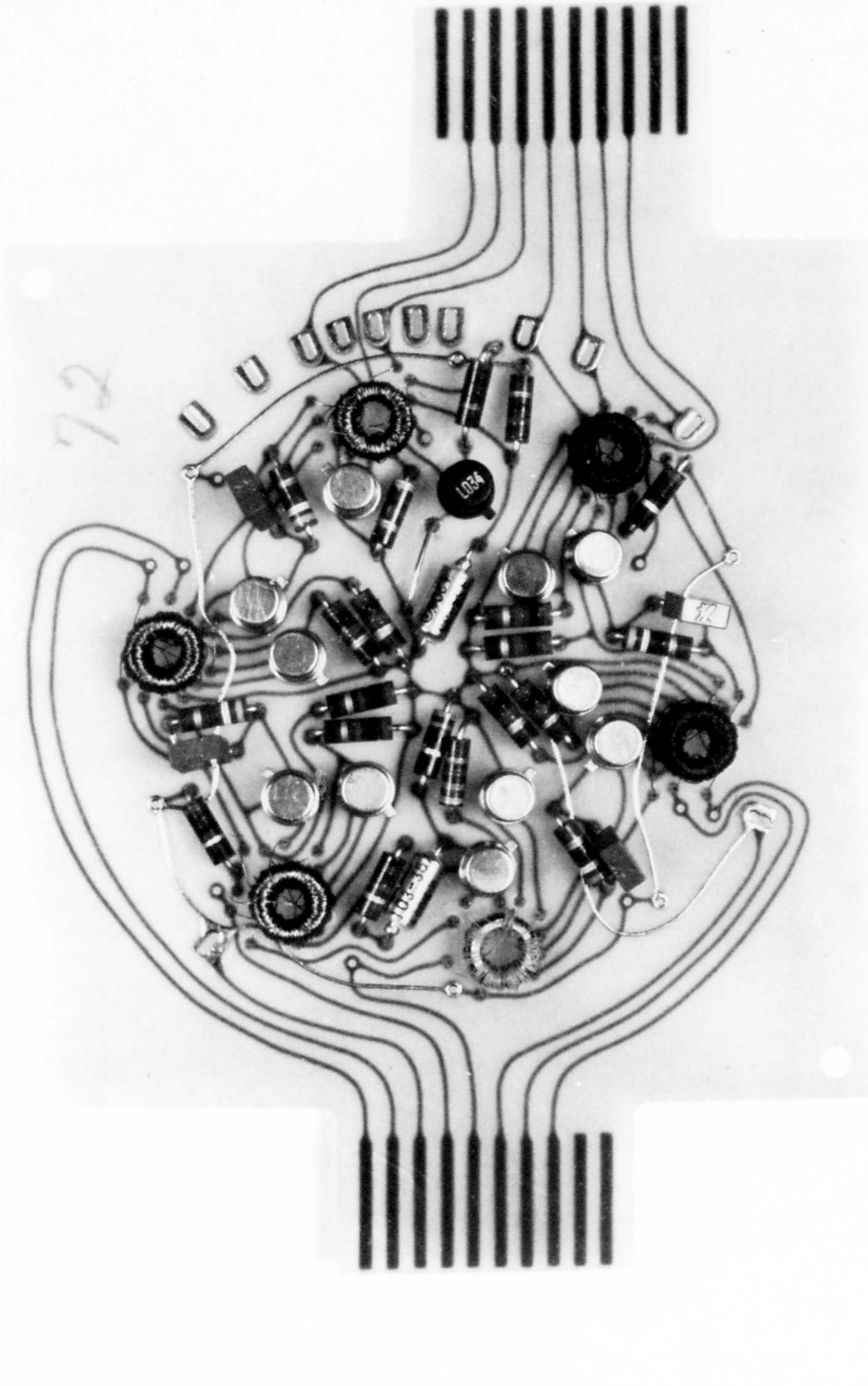

Figure 23. Decade-Counter Board

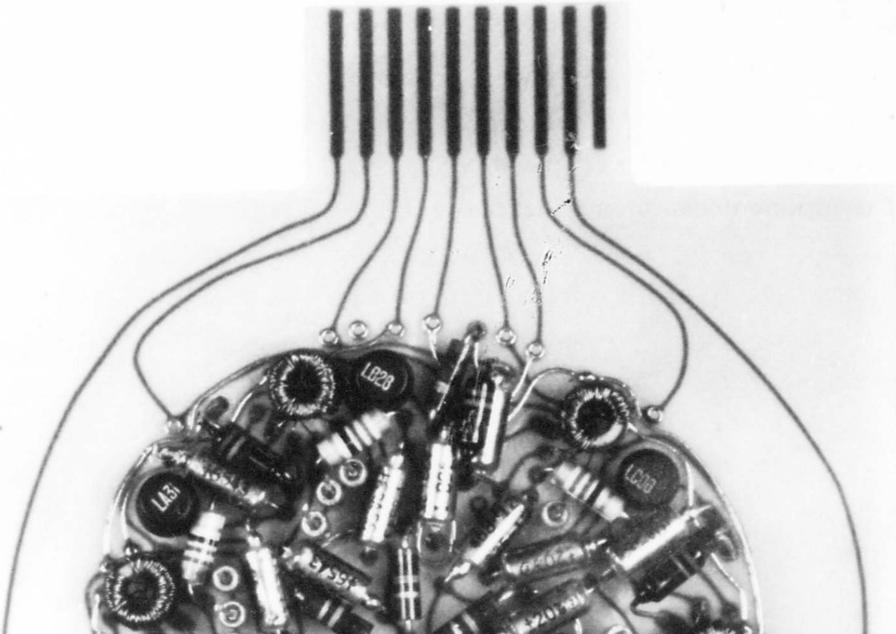

Figure 24. Bimag Counter Board

were set. Bench and flight testing of fuzes containing the revised circuitry during the final months of Phase II indicated the acceptability of this corrective action, and as a result the Phase III design was established based on the configuration of these last Phase II units.

Fabrication of the Phase III units was initiated in December 1965 and continued through May 1966. The electronics packages of these units underwent only minor change with the exception that the last 30 units incorporated a number of component changes to improve temperature operation.

The initiation of the first production contract on the FMU-35/B, during this same time period, resulted in additional producibility and operational changes being made in the design after the conclusion of the Phase III fabrication effort.

The following is a recapitulation of the major changes made during this period:

(1) In the Bimag Counter:

  (a) The diodes in the SCR gate circuits in each of the seven circuits of the module were eliminated, and the resistor (selected) was relocated to effectively create a low-pass filter and to make an adjustable threshold of the level at which the SCR switching is set.

  (b) The capacitance of the storage capacitors was increased to increase the switching energy.

  (c) Germanium diodes were replaced by silicon diodes to eliminate the problems inherent in the germanium diodes.

  (d) The cores were replaced by smaller cores that switch more easily.

(2) In the Decade Counter, values of various components were changed to stabilize the count ratios.

(3) In the Event Output Circuit, a diode was placed in the B+ leg of the anode circuit to block the capacitor network discharge

voltage from the anti-disturbance switch, preventing inadvertent event after arming.

(4) In the Impact Delay Module:

(a) Revisions were made in the delay-circuit portion of the module to ensure operation of the circuit.

(b) The entire module was modified to reduce current drain, provide a regulated, adjustable output voltage, and provide a higher output voltage.

(5) In the Arming Timer Module, minor component changes were made.

(6) In the Magnetic Oscillator Module, CRI was changed to establish better temperature characteristics.

Although additional minor changes were made during 1966, the electronics-package configuration remained very much like that shown in Figures 22, 23, and 24. The simplified system schematic as of 31 December is shown in Figure 25.

F. SAFING SWITCH

The initial fuze concept used the safing switch that was used on the FMU-26/B fuze at that time. This switch, shown in Figure 26, consisted of a spring-loaded ball, a Micro Switch precision switch, and appropriate linkage, and was designed to operate during an accidental shock of 60 g for 10 milliseconds. During initial testing, it was found that this concept would not be satisfactory since switch operation could not be relied on if impact occurred along the bomb axis. As a result, both FMU-35/B and FMU-26/B programs embarked on a development effort in which four switches using different principles of operation were designed, fabricated, and subjected to limited functional testing. Favorable test results were obtained with a design that consisted of a ball inertia weight, held between a cupped adjusting screw, and a spring-loaded plunger linked to a miniaturized switch. If the ball were subjected to a shock level in excess of the device threshold,

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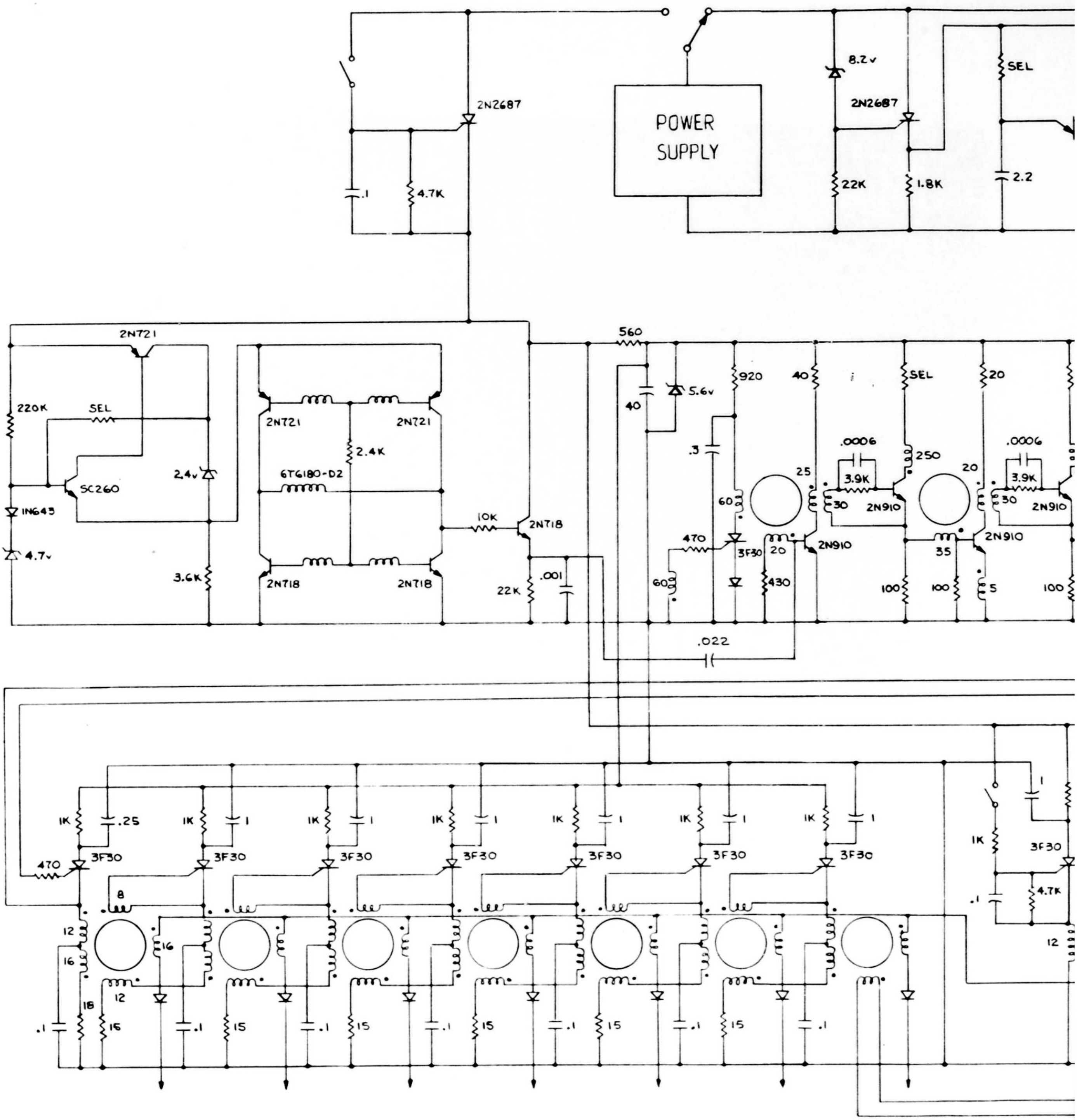

Figure 25. Simplified System Schematic

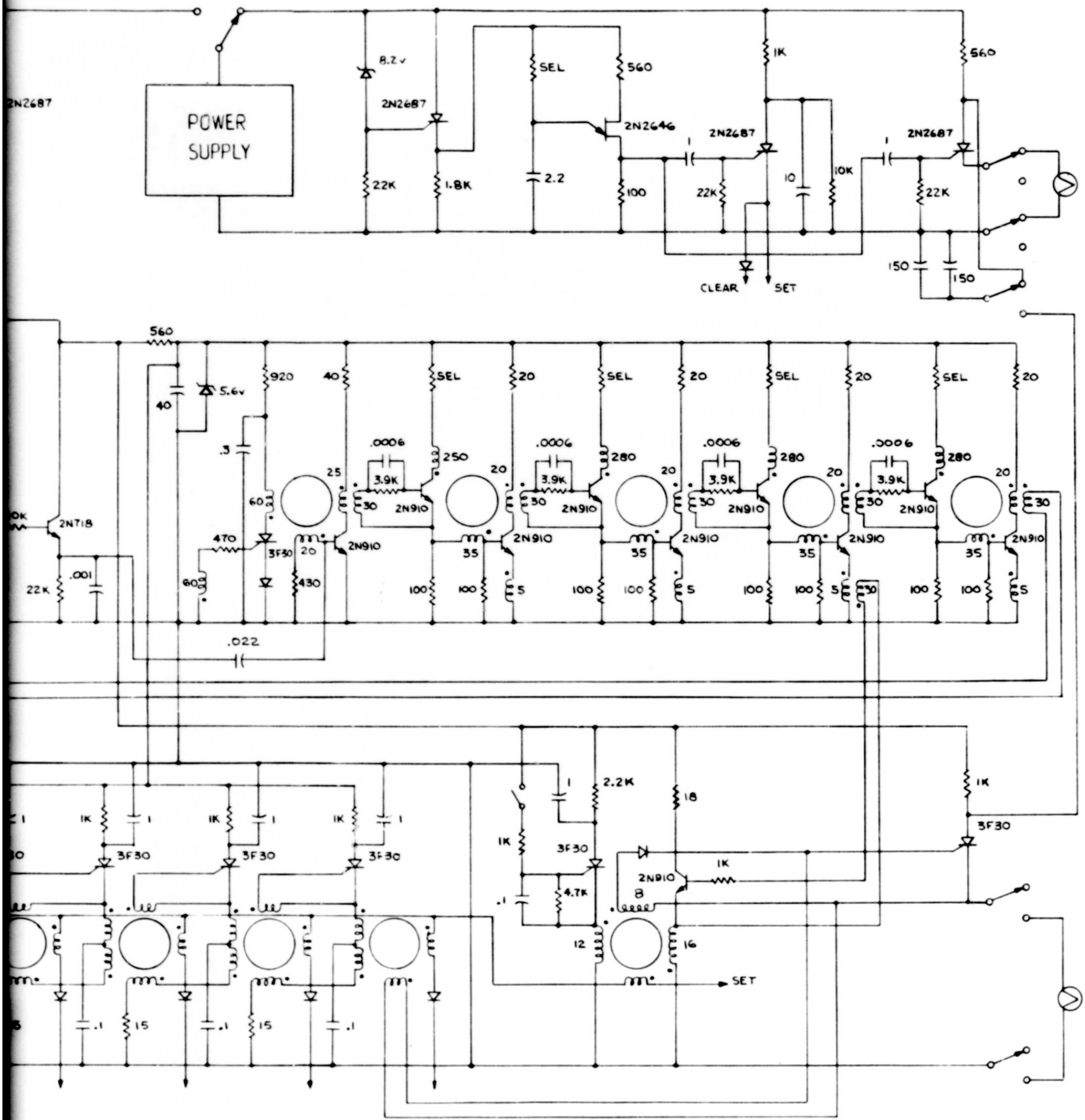

Figure 25. Simplified System Schematic

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in any direction except against the cupped adjusting screw, the ball would move out from between the plunger and screw. This action would cause the plunger to move axially, operating and latching the switch.

Minor refinements were made in the design briefly described in the previous paragraph to facilitate its integration into the explosive train. The miniaturized switch was replaced by a simple leaf-spring-type switch with a latching device, and the ball inertia weight was replaced by a cylindrical weight with a shaft. The switch is shown in Figures 26, 27, and 28. As initially used in the fuze concept, the switch was locked in the unoperated condition by a plunger which was held against the leaf spring by the safing plug when it was installed in the rotor housing. This protected the switch from accidental functioning during handling with the safe plug installed. However, it did not provide sufficient protection against the shocks normally incurred after the fuze was installed in the bomb.

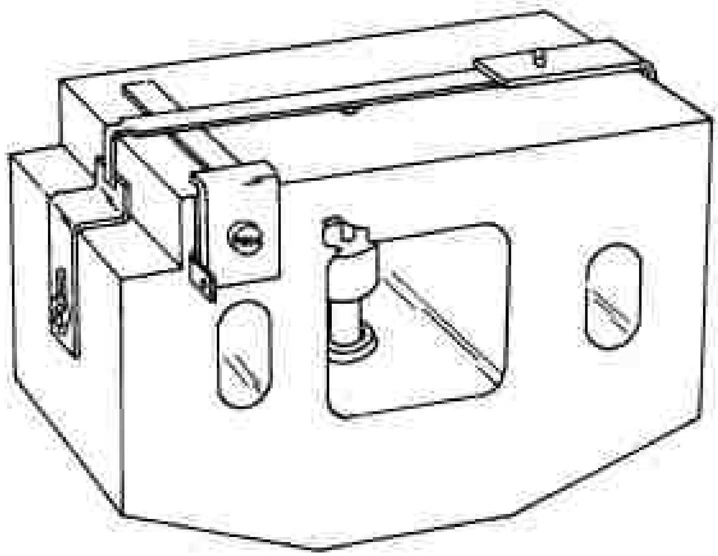


Figure 26. Artist's Concept of Safing Switch

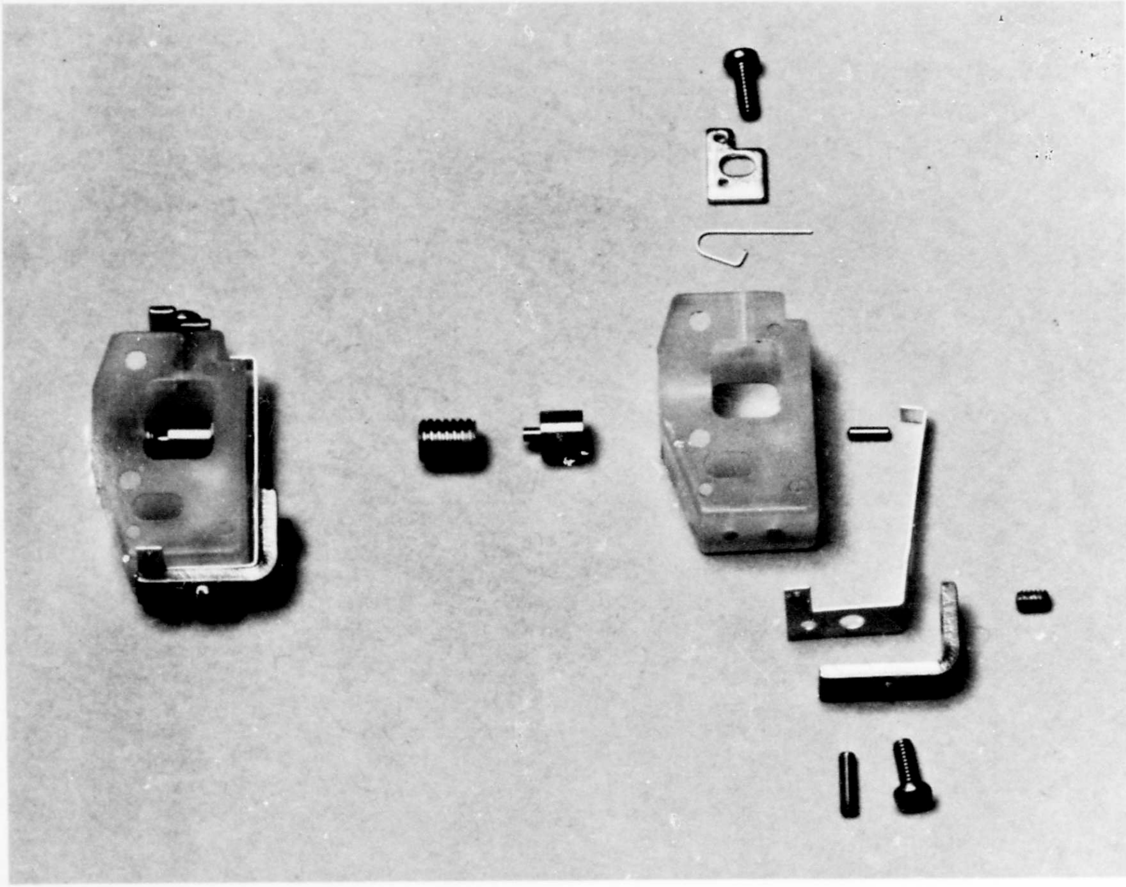


Figure 27. Typical Safing Switch (Sept. '64 to Sept. '66)

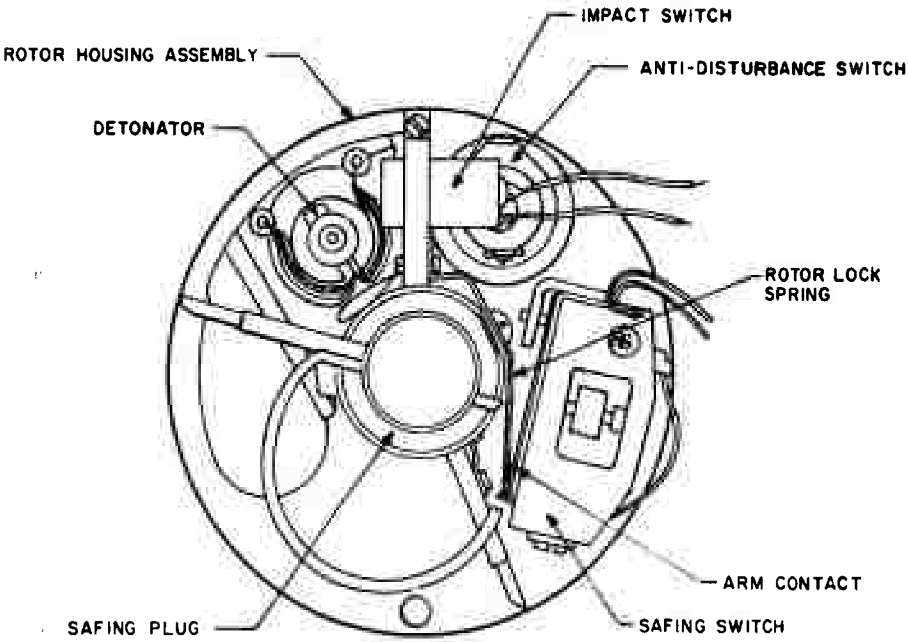


Figure 28. Typical Safing Switch Mounting in Rotor Housing (Sept. 1964 to Sept. 1966)

During the summer months of 1964, efforts were spent in modifying the safing-switch lockout function to reduce the possibility of inadvertent function during handling. The battery firing device and switch lockout mechanism were redesigned to provide an increased safing-switch threshold (approximately 400 to 500 g) when either the safing plug or unoperated battery firing device was installed in the fuze. This allowed reduction of the threshold to the normal functioning level of 50 to 120 g when the safing plug was removed or the battery firing device was operated.

In September 1966, investigations were conducted on the modification of the safing-switch lockout mechanism to reduce the chance of the safing-switch mass "popping out" under high-g shocks without activating the switch contacts. The improved design used a lockout spring which contacted the switch leaf spring at a point opposite the slug (Figure 29) rather than at the end of the leaf spring as in the earlier design (Figure 28). This latter design passed all required tests and was incorporated in the design at the end of 1966.

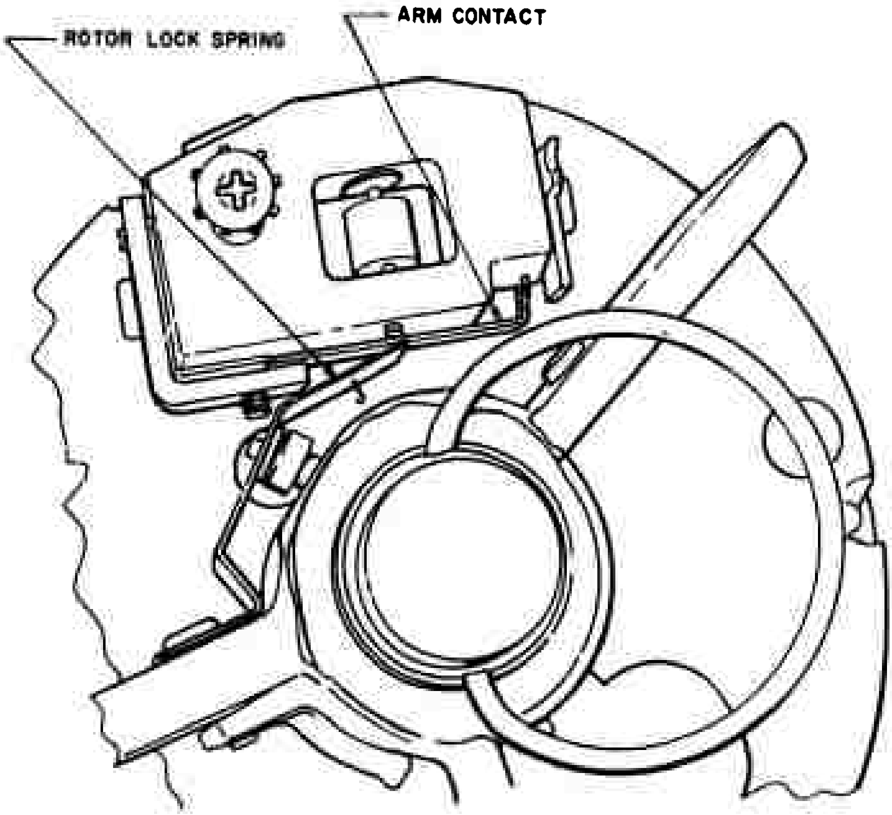


Figure 29. Typical Safing-Switch Mounting (December 1966)

G. IMPACT SWITCH

The impact switch, as developed under the FMU-26/B Bomb Fuze program, was appropriated for use in the FMU-35/B Bomb Fuze. Its function in the FMU-35/B is to close on bomb impact and initiate the impact delay circuit. After a 40-second delay, power is applied to the counters and allied circuitry, setting and starting the event delay time.

In the testing of six Phase I fuzes, the impact switches in two of the fuzes functioned on arming. During mechanical arming, two bellows motors rotate the rotor assembly approximately 90 degrees within 0. 1 second. Since a rotor stop abruptly halts the rotation, the shock effect functioned the impact switch which is located in the rotor housing. The switch was redesigned at this time to increase its operating threshold by shortening the blades (Figure 30). The increased threshold prevented switch actuation resulting from rotor shock.

H. ANTI-DISTURBANCE SWITCH

The prototype switch was completed in the first quarter of the contract (July-September 1963), and units were successfully subjected to sensitivity, shock, and transportation and aircraft vibration tests. The switch differed from that described in the proposal in that the internal spur gears were replaced by a printed circuit. Figure 31 shows this early form of the switch which was installed in the six Phase I prototype fuzes.

Following the Phase I production program, it was decided to return to the spur-gear configuration because gold tended to bead (Point 1, Figure 31) during the plating of the printed circuit, and some of the imperfectly plated samples tended to maintain a closed circuit. The spur-gear configuration is shown in Figure 32 and was used in the Phase II and Phase III switches. In some of the early models (October and November 1964) of this configuration, troubles were experienced with the end caps and nylon mounting screw fracturing at impact. Both items were strengthened.

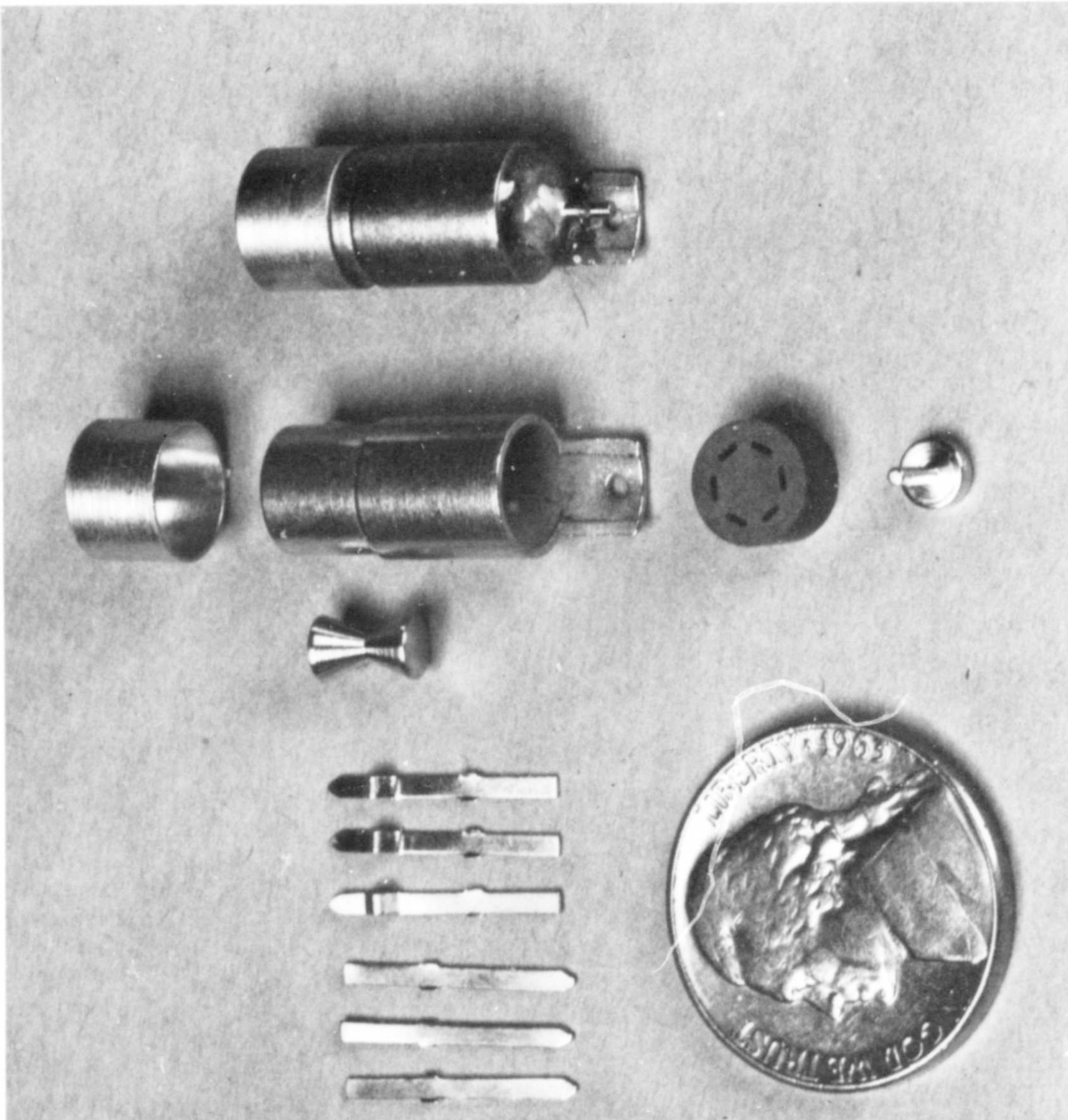


Figure 30. Impact Switch

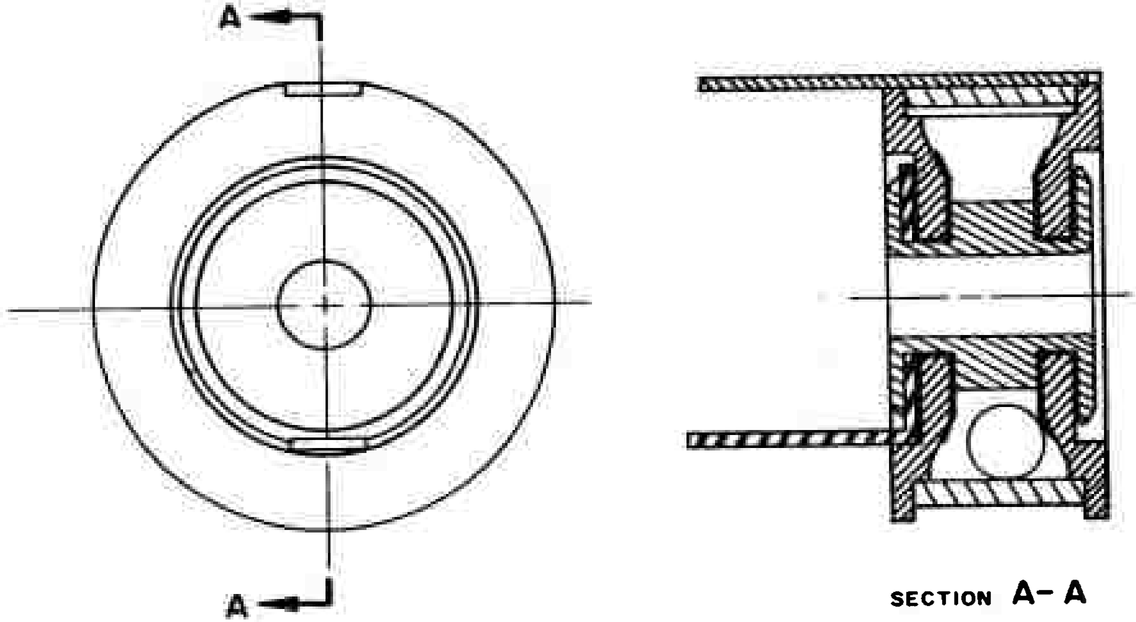


Figure 31. Anti-Disturbance Switch (Prototype)

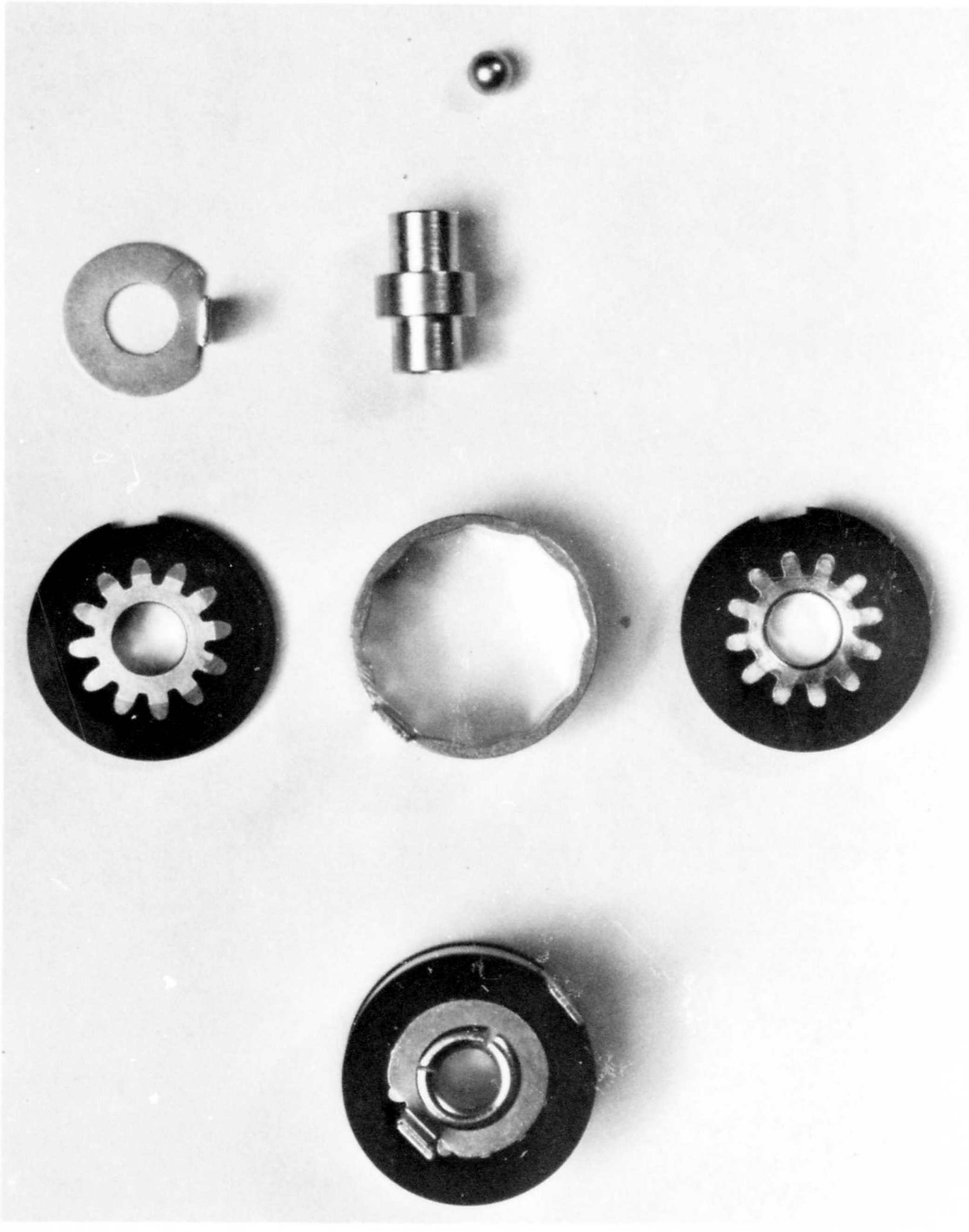


Figure 32. Anti-Disturbance Switch (Final Configuration)

The device consists essentially of two fixed contacts and a ball, arranged so that the ball completes the circuit between the two contacts only when the switch is disturbed. When the switch is at rest, the ball is positioned in one of the depressions of the shell and terminal assembly and cannot make contact with either of the gear-shaped contacts. If the switch is disturbed, the ball rolls over the high portions of the shell, making momentary contact with the gear contact.

In November and December of 1966, investigations were made in an attempt to increase the sensitivity of the switch. A two-fold attack was investigated: (a) make the switch itself more sensitive; and (b) make minor changes in the installation hardware so the slightest bomb disturbance or attempt to remove the fuze from the bomb would actuate the switch and result in bomb detonation. Several methods had been conceived by the end of the year. In one concept, the gear configuration of the switch would have been changed slightly to increase its sensitivity. This plan was dismissed because of a concomitant increase in the danger of sympathetic detonation. A second concept involved the incorporation of a dog in the nose which would cause the fuze to be turned in the well and consequently evented, if an attempt were made to remove the nose from the bomb. By year end, deliveries of the nose hardware had been completed; therefore, the change could not be incorporated during the R&D contract.

I. EXPLOSIVE TRAIN

The initial design of the explosive train was basically that of the FMU-26/B with these modifications:

(1) O-ring seals were added to the battery-firing-device well to provide sealing of the fuze assembly.

(2) Provisions were made for mounting the impact switch and anti-disturbance switch on the housing in addition to the safing switch.

(3) The switching portion of the assembly was changed to provide the switching functions required by the electronics assembly at arming.

The initial and the terminal design both consist of the following major components and subassemblies which perform the following functions:

(1) Contact Plate — Contains the switch contacts for switching the bellows-actuator circuits, event output circuits, etc., that take place at arming and eventing.

(2) Rotor Assembly — Consists of the rotor, bellows actuators, electric detonator, and printed-circuit wiper plate. The latter completes the required circuits in the contact plate.

(3) Rotor Housing — Provides the mounting structure for the rotor assembly and contact plate. The switches, Item 2 of the first paragraph, are mounted on the housing at a later stage of assembly.

The explosive train assembly as completed for the Phase I fuzes in November 1963 is shown in Figure 33; the rotor and contact plate are shown in Figure 34.

After completion of the FMU-35/B Phase I units, the FMU-26/B testing program revealed that the size of the booster had to be increased to 45 grams. This necessitated redesign of the FMU-35/B explosive train for the Phase II units.

During the course of early Phase II flight testing, failure analyses showed that the structural and functional integrities of the explosive train assembly were inadequate. Damage to the assembly was caused by the electronic package and battery impacting against the explosive train contact ring at bomb impact and, in several cases, the devices did not fully arm.

Due to this, the mechanism was redesigned. The redesign involved removing the rotor-housing castellations to provide a flat surface, and adding a 0.075-inch steel plate on that surface. In addition, the contact ring was redesigned and assembled as an integral part of the rotor assembly. The method of driving the rotor to the in-line position was changed by replacing

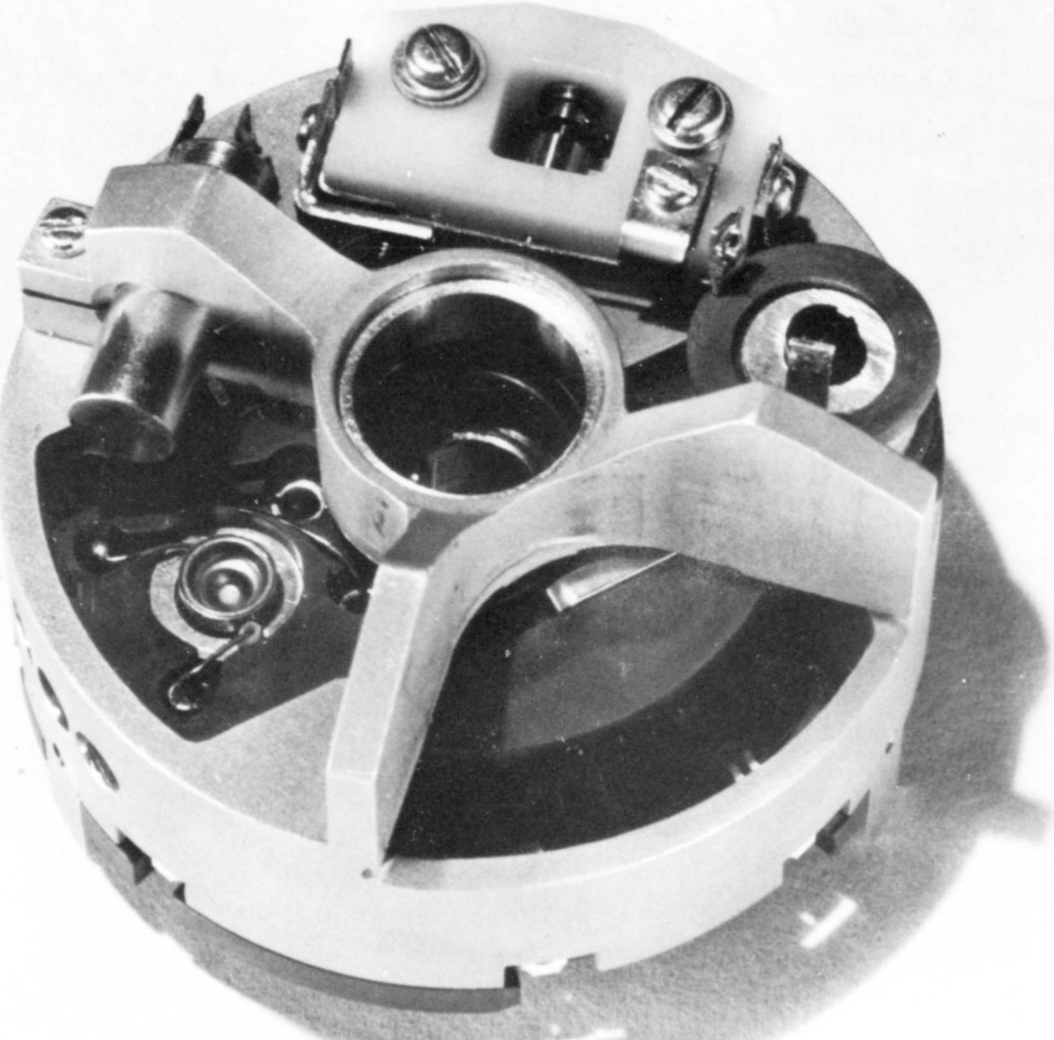


Figure 33. Explosive-Train Assembly

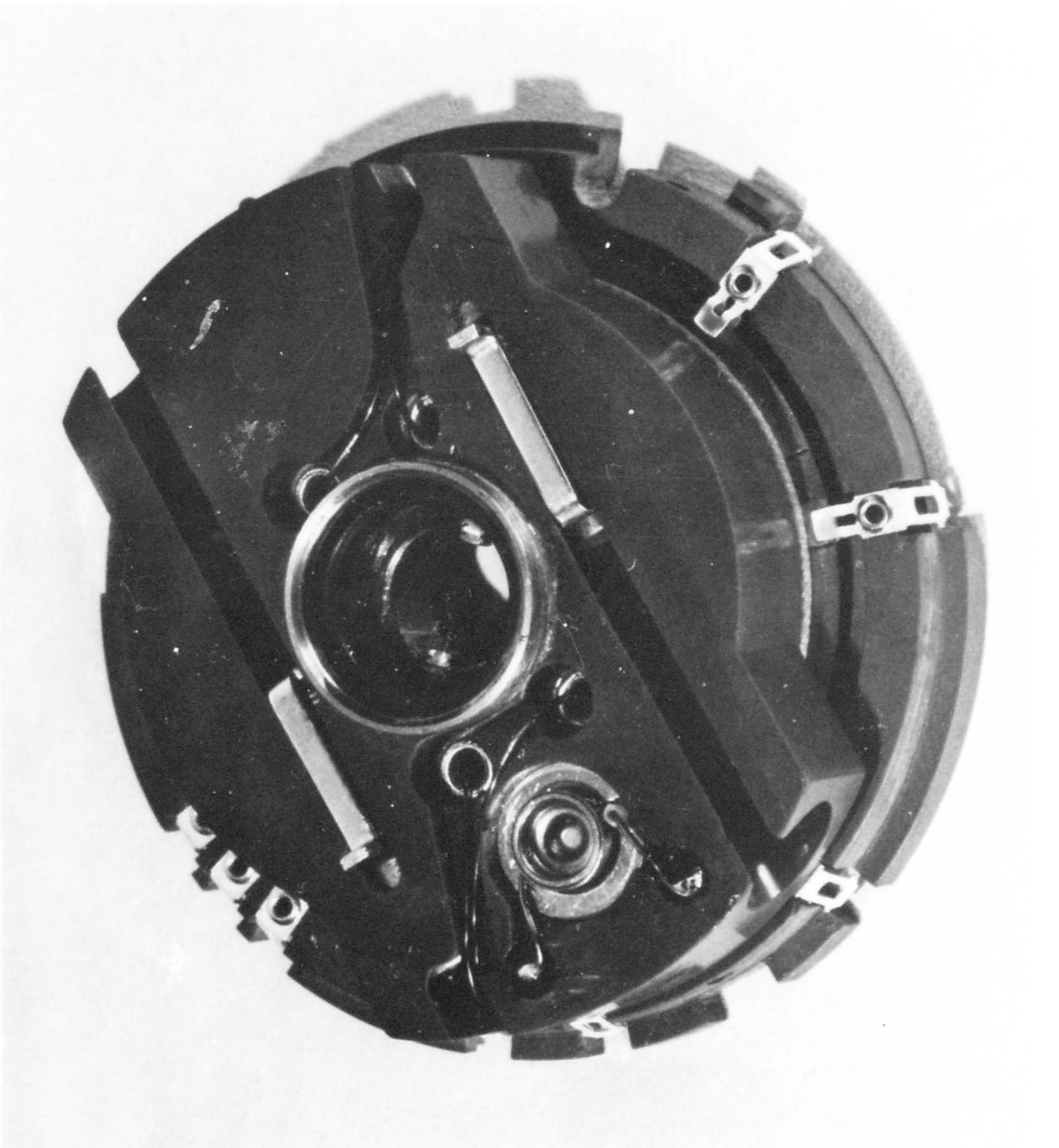


Figure 34. Rotor and Contact-Plate Assembly

the formed clip with a piston assembly to provide a more positive drive. In drop tests of three units, a sled test of one unit, and flight tests of six units, the integrity of the rotor assembly was adequate. Figures 35 and 36 show this explosive-train and rotor-assembly design which remained unchanged for the remainder of the program.

J. BOOSTER

During the early period of FMU-35/B development, a question arose about the inability of the FMU-26/B and FMU-35/B booster pellets (15.4 gm) to cause high-order detonation if the fuze were installed in the nose well of the bomb. This questioning was based on preliminary testing of FMU-26/B and 30/B boosters at Eglin AFB.

Testing of boosters in December 1963 indicated that a 45-gm booster was adequate and could be used in the FMU-35/B. As a result, the explosive train was redesigned to accept the larger booster. Figure 37 shows the final design of the booster. The booster is taped in a recess of the fuze container and located immediately above a plugged hole in the container. When in the armed position, the detonator rotates to a position directly below this plugged hole. Upon firing of the event output SCR, the detonator explodes through the container plug and into the booster to detonate it high order.

K. FUZE ASSEMBLY

1. Description

The FMU-35/B fuze assembly is pictured in Figure 38. The assembly is made up of the following four major subdivisions.

a. Explosive Train Assembly (Figures 35 and 36).

Figure 35. Explosive-Train Assembly (Final Design)

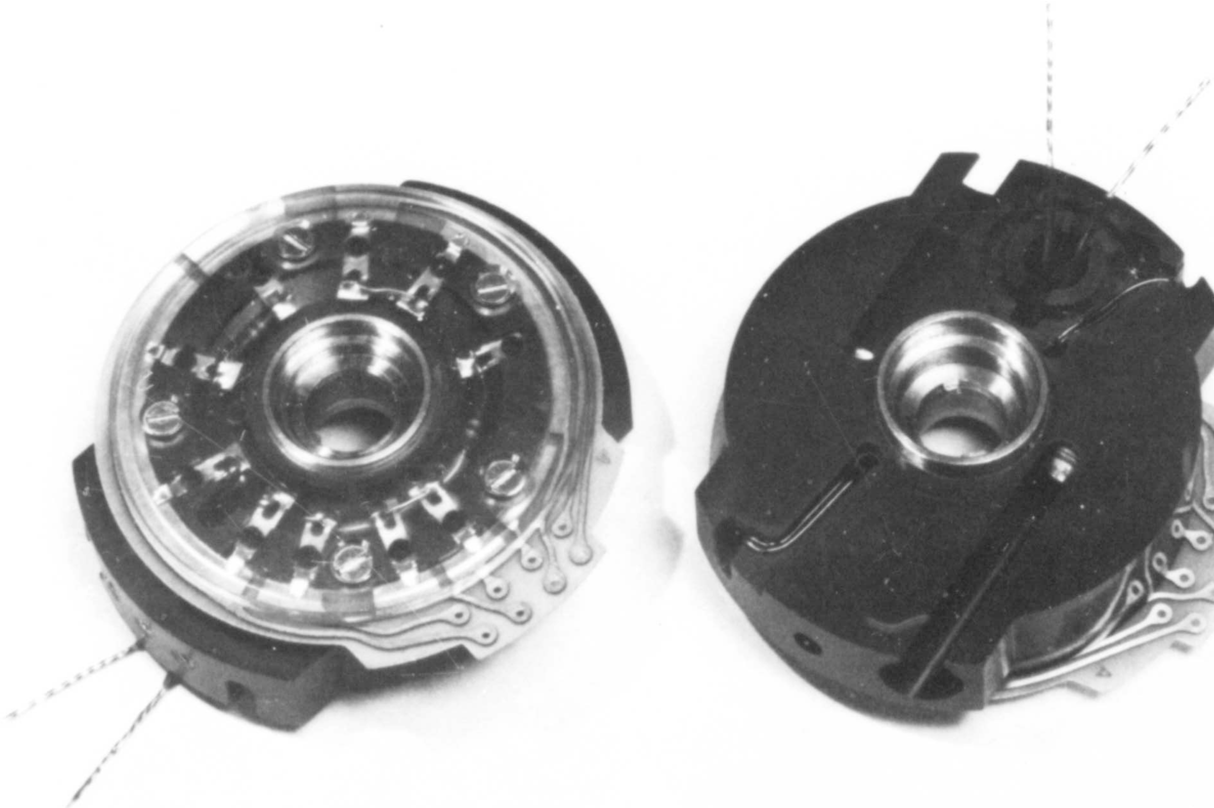


Figure 36. Rotor and Contact-Plate Assembly (Final Design)

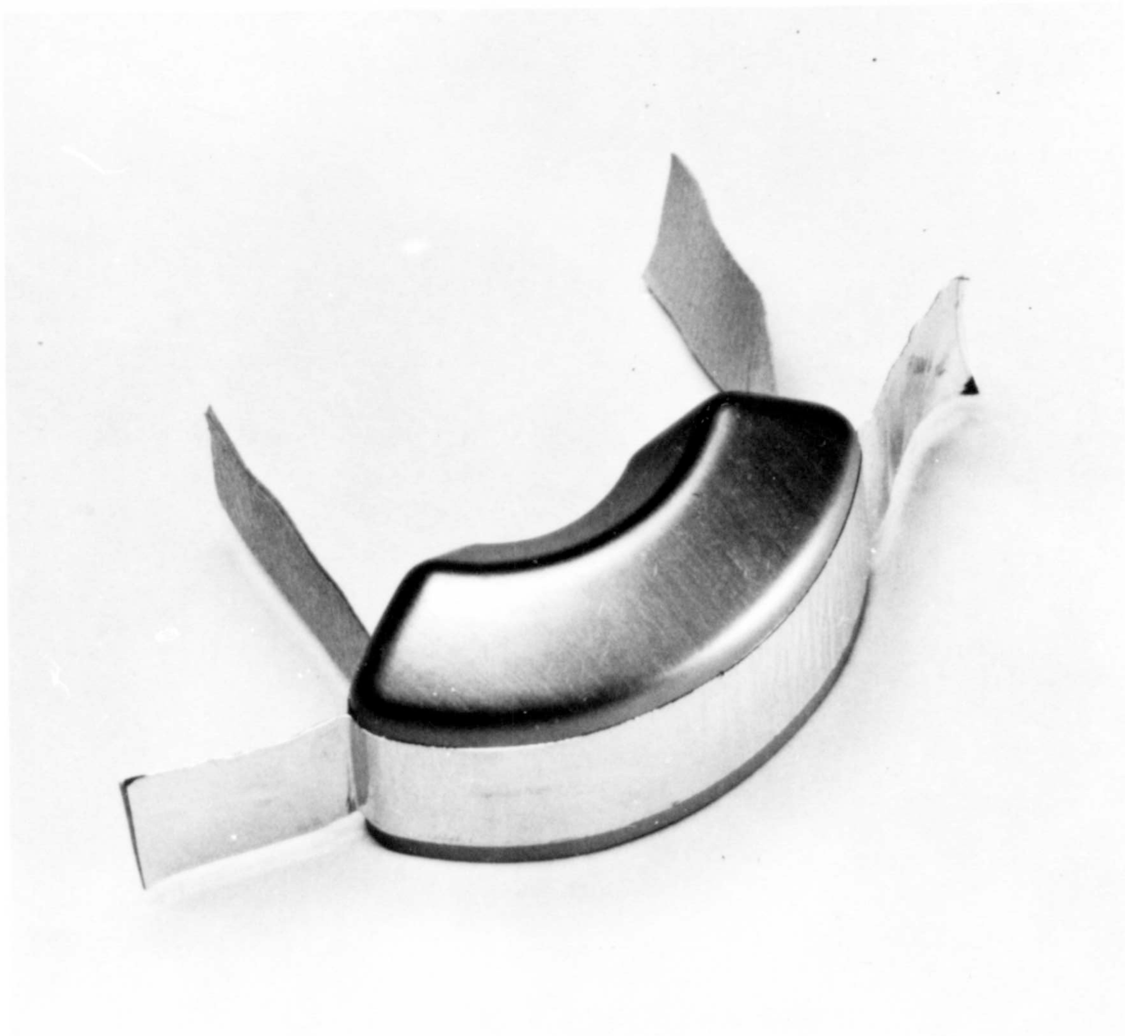


Figure 37. Booster and Tape Assembly

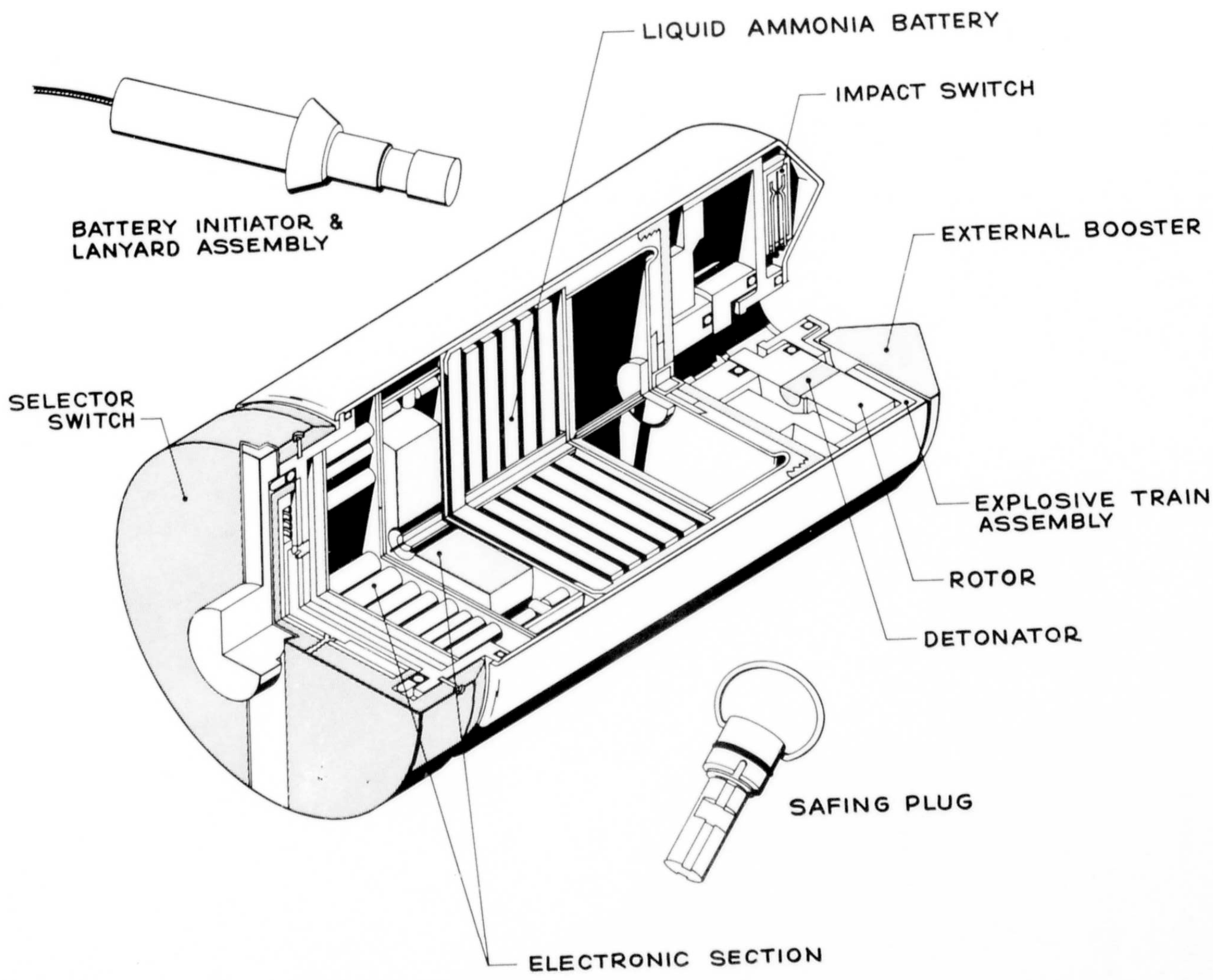


Figure 38. Artist's Concept of Fuze

b. Potted Electronic Package (Figure 39). This assembly consists of the decade-counter boards, the bottom-board assembly, the ammonia battery, and the selector-switch housing assembly. It is potted in epoxy to provide a rigid subassembly capable of withstanding the impact environment.

c. Fuze Container and Baffle Assembly (Figure 40). This assembly is a drawn-steel can with a baffle welded in place.

d. Selector Switch Cover Assembly (Figure 2). Figure 41 shows the component and subassembly makeup of this fuze, as well as step-by-step assembly of the fuze. Final assembly consists of installing the detonator in the rotor-switch assembly; attaching the electronics assembly to the rotor housing and rotor-switch assemblies; adding the safing switch, anti-disturbance switch, and impact switch to the rotor housing; inserting the assemblies interconnected thus far into the container and baffle assembly; crimping the container over the flange on the selector switch housing; and attaching the selector-switch cover assembly.

2. Fuze Fabrication

Fabrication of fuzes for the three phases of the AF-3745 contract is summarized in Table II:

Figures 42, 43, and 44 are photographic views of the FMU-35/B fuze. The first two show the fuze prior to enclosing in the container and baffle assembly; Figure 44 shows the complete fuze, ready for enclosure in a metal shipping container.

3. Description of Fuze Operation

Table III provides a concise summarization of the fuze operation from preselection of the time delay to bomb detonation. The list of operations in Column I can be read separately or in conjunction with the items in Column II. This will allow a quick look, or a broad view, of fuze operation, as required.

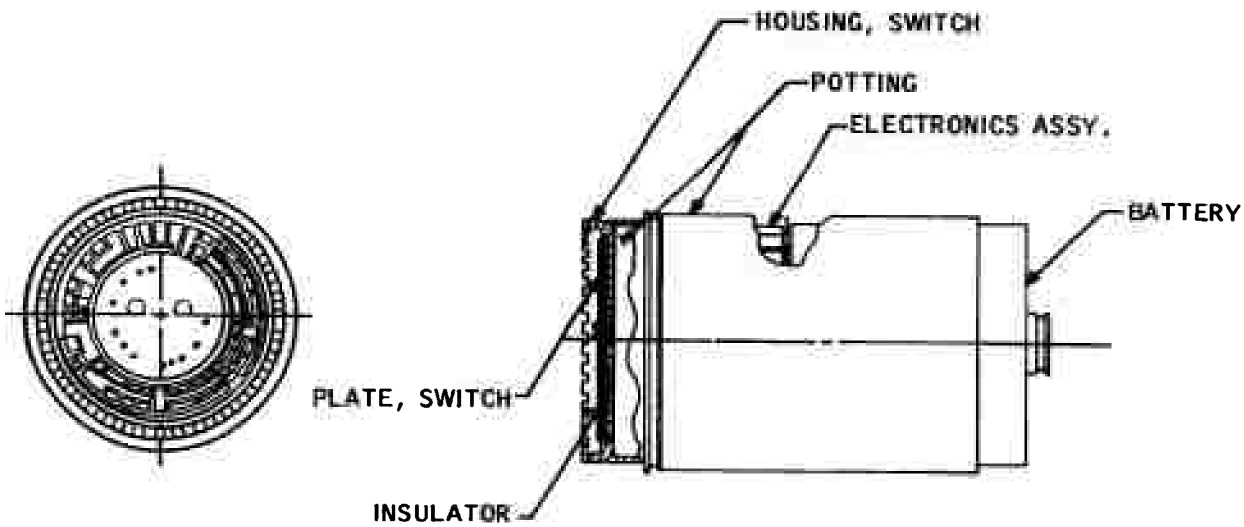


Figure 39. Electronics Assembly, Potted

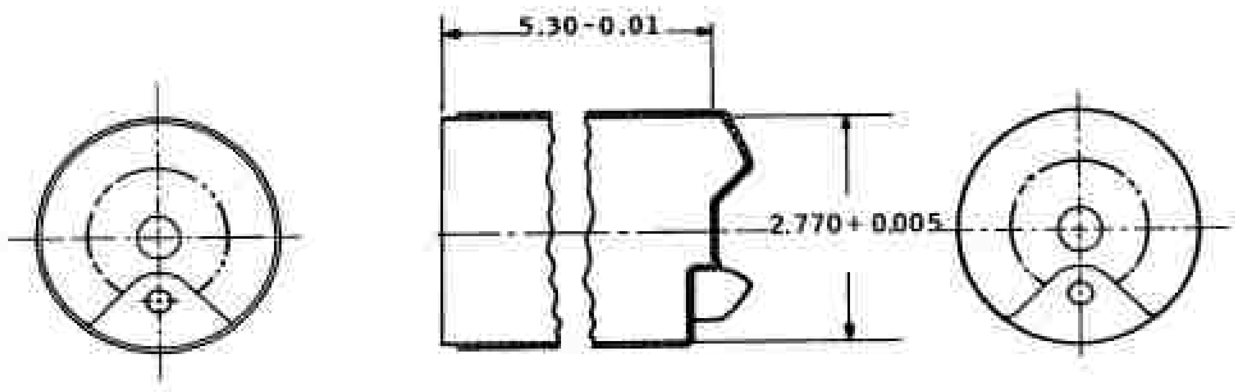
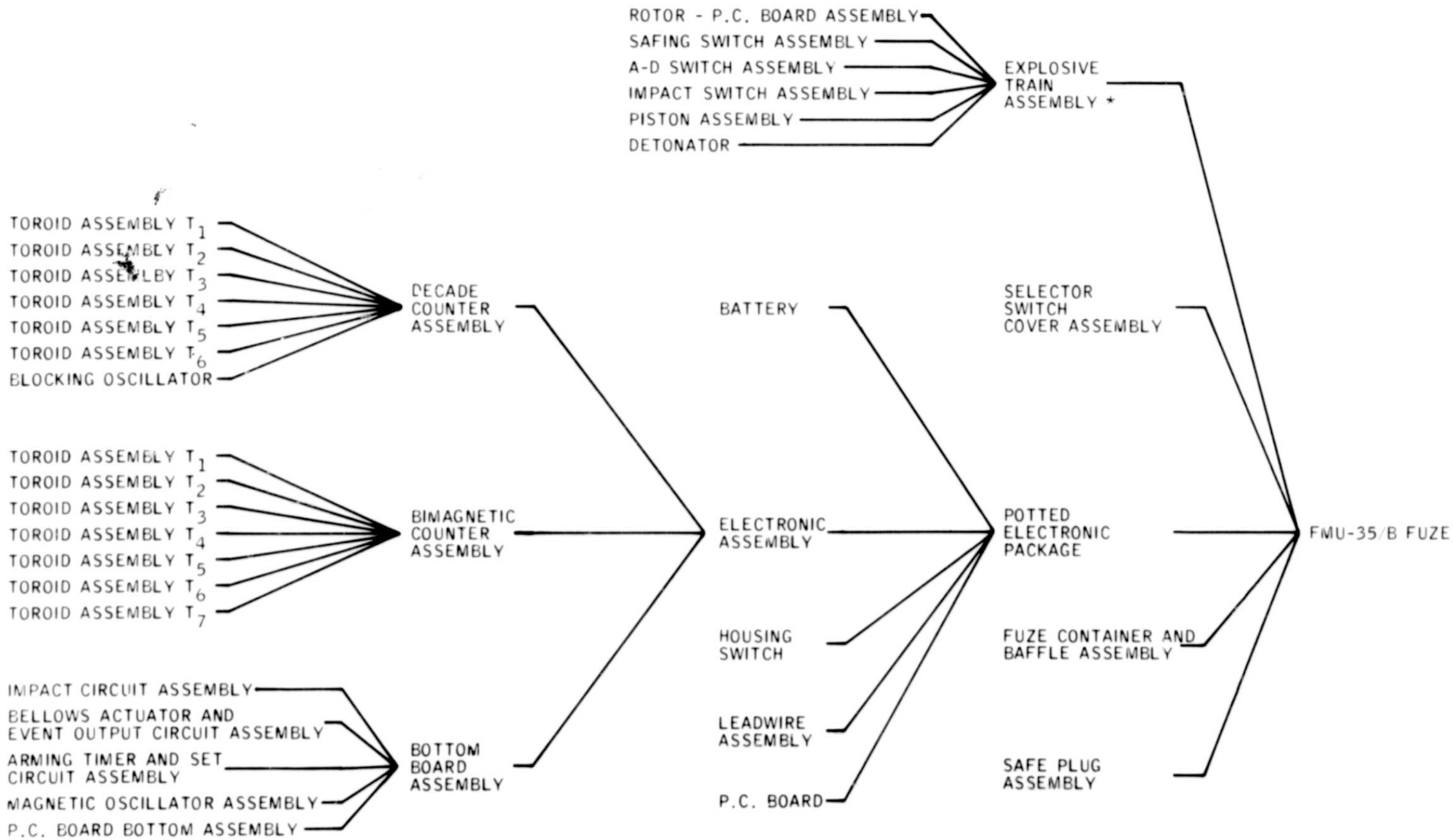


Figure 40. Fuze Container and Baffle Assembly



* THE SIX SUBASSEMBLIES OF THE EXPLOSIVE TRAIN ARE ASSEMBLED INTO THE FUZE AT THE SAME TIME AS THE ITEMS DIRECTLY BELOW "EXPLOSIVE TRAIN ASSEMBLY".

Figure 41. FMU-35/B Assembly Diagram

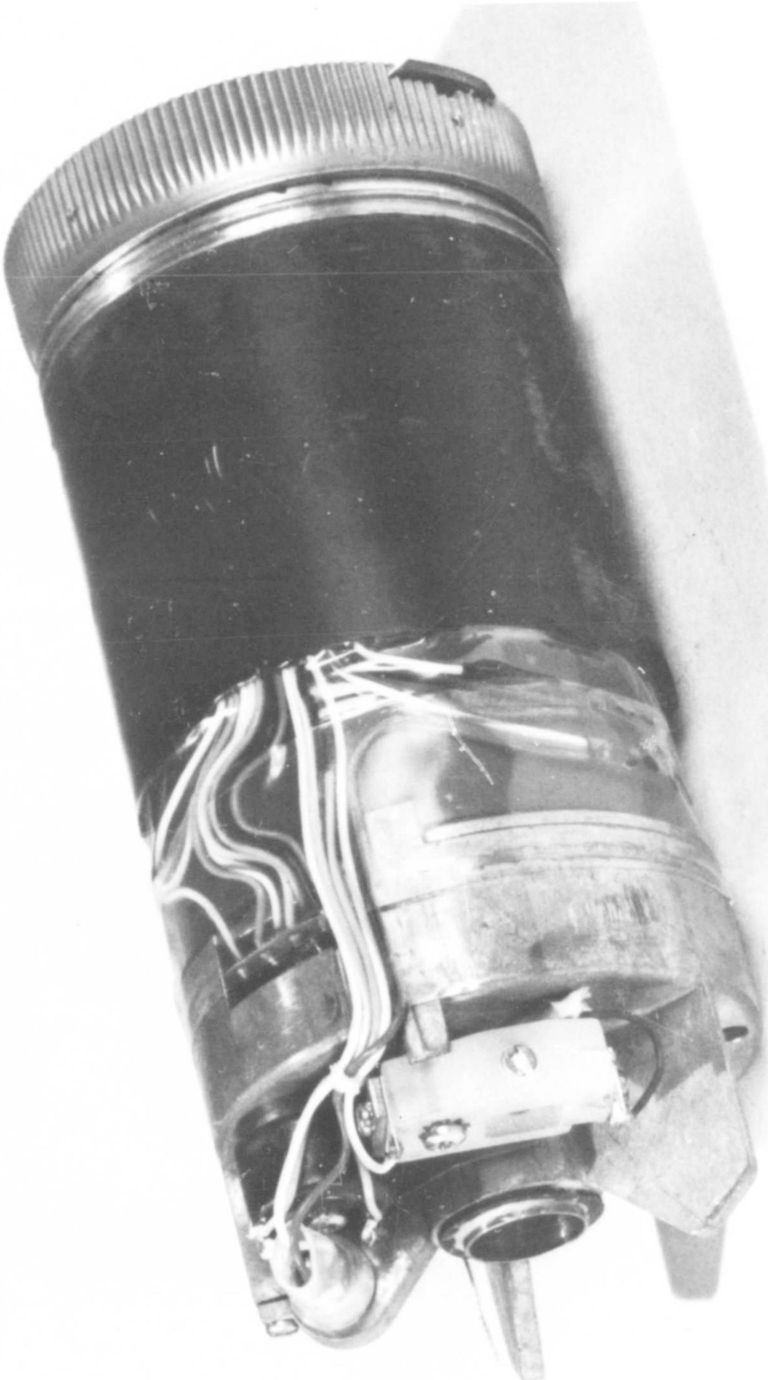


Figure 42. Explosive-Train-End View of FMU-35/B Fuze Before Placement in Container

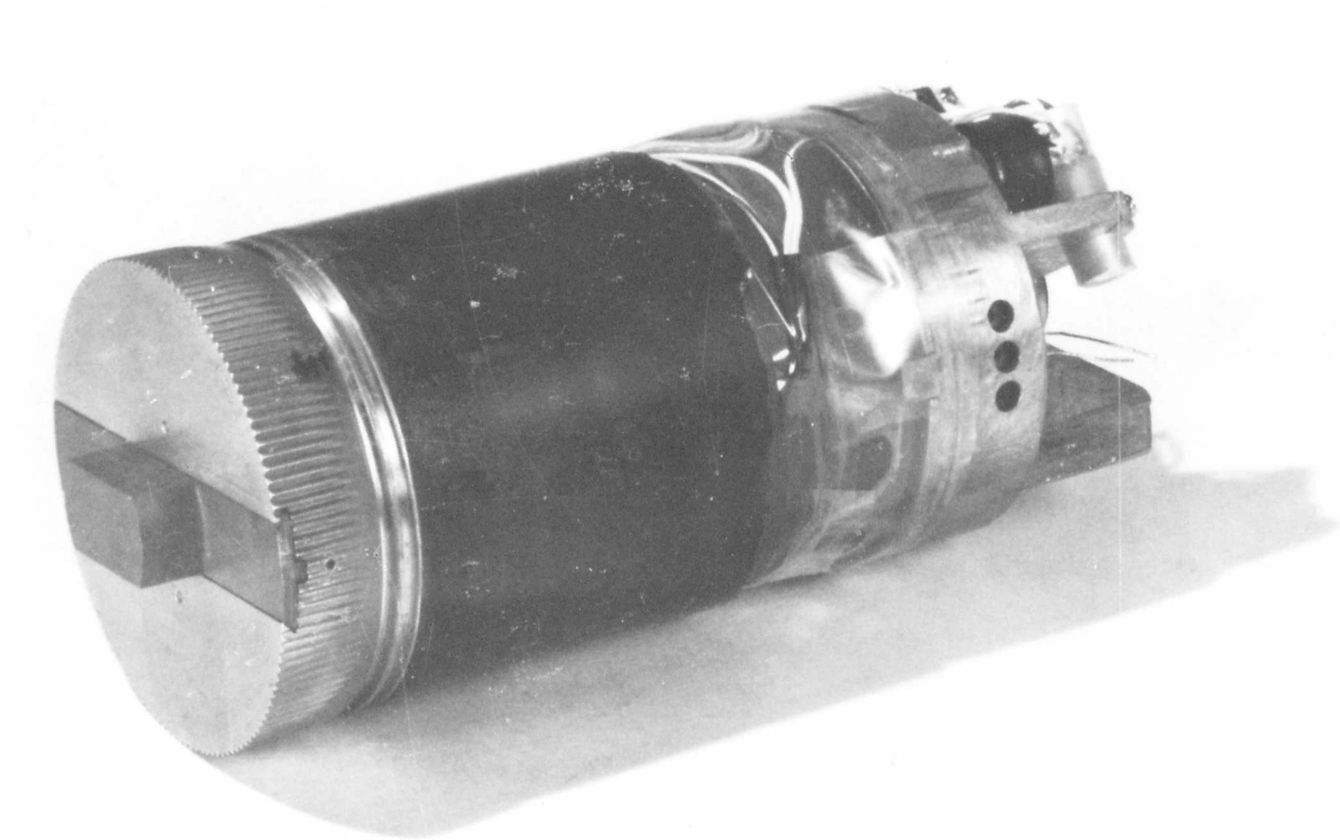


Figure 43. Setting-Knob-End View of FMU-35/B Fuze Before Placement in Container

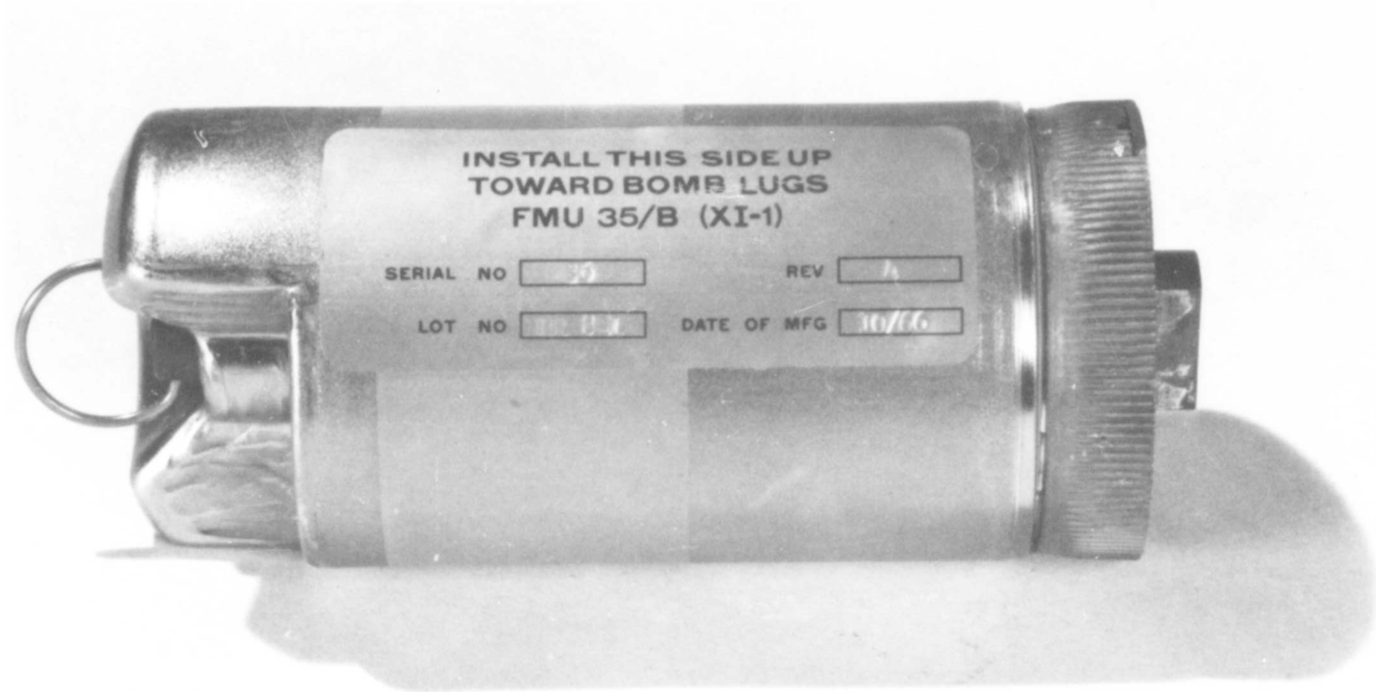


Figure 44. Complete FMU-35/B Bomb Fuze

TABLE II. SUMMARY OF FUZE FABRICATION

Contract Phase	No. Fuzes Fabricated	Date of Completion	Comments
I	6	Jan. '64	Fuzes contained (a) dummy plugs to simulate ammonia batteries; (b) explosive trains with 15-gm booster capacity; and (c) impact switches modified to prevent activation at mechanical arming.
II	150	Oct. '65	All fuzes had boosters of 45-gm capacity. Forty fuzes containing simulated batteries and electronic packages were fabricated for 30 out-of-line tests and ten flight-test, structural tests. One hundred ten functional, instrumented fuzes were fabricated for laboratory and flight-tests.
III	400	5 June'66	Fabrication for Eglin Air Force Base engineering evaluation categorized as follows: Instrumented . . . . . 120 With D. M. and A-D Ckt. Active - 45 With Det. and A-D Ckt. Active - 75 Out-of-Line . . . . . 7 Tactical . . . . 273 With Det. and A-D Ckt. Inactive - 153 With D. M. and A-D Ckt. Active - 120 Total . . 400

TABLE III. SEQUENCE OF FUZE OPERATION

Column I Operation	Column II Aircraft Controls, Bomb Parts, and Fuze Subassemblies Affected
1. Function delay time is set.	1. Selector switch assembly.
2. Fuze is installed	2. Fuze; bomb fuze well.
3. Bomb is airborne.	3. Aircraft flight controls.
4. Bomb is dropped "armed" when arming ring is held; lanyard cable is pulled out of bomb through arming ring, and fall with the bomb; and battery initiator is fired	4. Ring of swivel and link assembly; aircraft arming solenoid; lanyard cable of BFD; battery initiator of BFD.
OR	
4a. Bomb is dropped "safe" when arming ring is released, and lanyard cable and arming ring fall with bomb.	4a. See 4. above.
5. Battery voltage rises to normal when battery is activated; arming delay time starts.	5. Battery
6. Power is made available to arming ckt., clear-set ckts., and impact-switch ckt.; arming timer is activated and completes 1. 85 sec arming delay.	6. Battery; arming ckt.; clear-set ckts.; impact-switch ckt.
7. Bellows actuators remain connected to arming output ckt.; detonator leads are shorted for safety.	7. Bellows actuators; rotor switch; arming output ckt.; detonator.
OR	
7a. Safing switch ckt. to bellows actuators opens if premature bomb impact occurs before arming delay elapses, dudding fuze.	7a. Safing switch.

TABLE III. SEQUENCE OF FUZE OPERATION (continued)

Column I Operation	Column II Aircraft Controls, Bomb Parts, and Fuze Subassemblies Affected
8. Arming delay elapses when arming output ckt. discharges through normally closed safing switch.	8. Arming delay ckt. ; arming output ckt. ; safing switch.
9. Bellows actuators fire and rotor switch turns 90 degrees.	9. Rotor assembly.
10. Detonator is aligned; short on detonator leads is removed; ckt. to detonator is completed.	10. Rotor switch of rotor assembly; detonator; event output ckt.
11. Bomb hit closes impact switch, initiating impact delay ckt.	11. Impact switch; impact delay ckt.
12. When 33-sec impact delay elapses, power is supplied to time base oscillator, counter, event output ckt., A-D switch, and clearset line.	12. Impact delay ckt. ; battery; delayed B+ ckt. ; time base oscillator; event output ckt. ; A-D switch.
13. Desired event delay time is set.	13. Preset ckt. ; magnetic counter.
14. Preset event delay time starts.	14. Time base oscillator; magnetic counter.
15. When preset event delay elapses, magnetic counter emits pulse to event output ckt.	15. Event delay ckt. ; magnetic counter; event output ckt.
15a. If bomb is disturbed before event delay time elapses, A-D switch closes to event output ckt., triggering event output ckt.	15a. A-D switch; B+ delay ckt. ; event output ckt.
16. Pulse from event output ckt. fires electric detonator.	16. Event output ckt. ; electric detonator.

TABLE III. SEQUENCE OF FUZE OPERATION (concluded)

Column I Operation	Column II Aircraft Controls, Bomb Parts, and Fuze Subassemblies Affected
17. Booster is initiated by electric detonator.	17. Electric detonator; booster.
18. High explosive of bomb is initiated by booster, and bomb explodes.	18. Booster; bomb H. E.

SECTION IV

TECHNICAL DETAILS - EVALUATION PROGRAM

A. GENERAL

A comprehensive program of evaluation was engaged in by the contractor, the ammonia-battery subcontractor, and the Air Force personnel at Eglin Air Force Base during the course of the design and development of the FMU-35/B Bomb Fuze. The evaluation program for the three and one-half year period included the following:

1. <u>Phase I - Development Tests</u>

   a. Environmental tests on fuze components.

   b. System tests, compatibility tests, and pre-qualification tests (simulated flight, environmental, and safe handling tests) on fuze assemblies.

2. <u>Phase II - Qualification Tests on Assemblies</u>

   a. Environmental tests.

   b. Functions tests.

   c. Out-of-line safety tests.

   d. Flight tests.

   e. Ejection-rack tests.

   f. Acoustical noise.

   g. Safety tests.

3. <u>Phase III - Air Force Tests on Assemblies</u>

   a. Flight tests, including sled tests.

   b. Environmental tests.

Phase I and Phase II tests were also conducted on the subcontracted, liquid-ammonia batteries. These tests are described in Part D, Section III, the discussion of battery design and development.

The following paragraphs summarize the evaluation programs carried out during the course of the design and development of the fuze. The summary is divided into three parts, based on the programs carried out during Phase I, Phase II, and Phase III of the contract.

B. PHASE I EVALUATIONS

1. Test Plan

An evaluation plan for Phase I was completed in November 1963. It was closely patterned after the plan submitted in the proposal in May of the same year. Table IV lists the planned tests along with an indication of the number of tests to which each of the six fuzes would be subjected and the sequence in which the tests would be conducted.

2. Evaluation of Results of Phase I Testing

Evaluation of the results obtained in the testing of the six Phase I fuzes was completed in April 1964. It showed that while the Phase I design provided a fuze which was safe during and after the tests, it had several functional deficiencies. These deficiencies and the corrective actions taken to prevent their recurrence in the Phase II design are summarized below.

a. The clear-set circuit was inadequate to ensure complete clearing of the decade counter. This problem was corrected in the Phase II design by modifying the circuit and changing the type of diode used.

b. The electronic counters were inoperative at low temperature (-65°F). This problem was the result of freezing the design of these units

TABLE IV. PHASE 1 TEST PLAN

Test	Fuze Unit No.					
	1	2	3	4	5	6
Functional (Rebuild)	1, 5	1, 5	3	3	3	
High Temperature	2			2		
Transportation Vibration	3		1			1
Aircraft Vibration	4	4				2
Temperature & Humidity	6	6				
Functional	7	8	5	5	5	3
Thermal Shock		2				
Altitude & Altitude Change		3				
Immersion		7			2	
Low Temperature			2		1	
Jolt			4	1		
Jumble				4	4	

NOTES:

a. The functional test simulates an actual bomb-drop test.

b. Numbers in columns indicate the sequence of the test.

prior to completion of the breadboard testing, and continued to be a development problem even into the early stages of Phase II design. In May 1964, the design was such that Phase II fuzes would be operable at the temperature extremes, but the accuracy would decrease up to 20 percent.

c. Impact shocks caused the fuzes to event prematurely. The problem was resolved by adding noise filters to the electronic counters at the input to each decade-counter stage. When a partial mockup of the modified system was shock tested, it was found to be capable of proper operation at shocks up to 25,000 g. The modifications were incorporated in the Phase II design.

d. The explosive-train rotor did not go fully in-line at mechanical arming in all cases due to interferences which bound the bellows-actuator clips and jammed the rotor. This problem was rectified in the Phase II design by replacing the bellows-actuator clips with pistons.

e. The impact switch inadvertently functioned at mechanical arming on two units. The Phase II impact switch was modified to alter its threshold characteristics so the switch would not operate as a result of the rotor shock which occurs at mechanical arming.

f. Following the temperature and humidity tests, the selector switch was difficult to operate. This was due to a partial decomposition of the plastic dials used on these units. Aluminum-tape dials, not subject to this problem, were specified for the selector switch in the Phase II units.

C. PHASE II EVALUATIONS

The testing program for Phase II was identified as a qualification program. Components used in the fabrication of the test units were not to be qualified as separate items, but the extensive development tests and system qualification tests were to provide assurance of reliability for the components.

Destructive and non-destructive tests were performed during the course of the qualification program. The destructive tests were performed last in the order of environmental sequence so maximum information could be obtained from each test performed. Engineering judgment and availability of units were used to determine the order of environmental testing. Field tests at the Eglin Air Force Base test facilities were also conducted.

The following tests were performed during the period July 1964 through December 1965:

1. <u>Non-Destructive Tests</u>

High Temperature	Mechanical Shock
Low Temperature	Five-Foot Drop
Thermal Shock	Altitude and Altitude Change
Temperature and Humidity	Immersion
Aircraft Vibration	Salt Spray
Transportation Vibration	Acoustical Noise

2. <u>Destructive Tests</u>

   Jolt
   Jumble
   Forty-Foot Drop

3. <u>Functional Tests</u> (Simulated Flight)

4. <u>Static Firing Tests</u>

5. Field Tests

Functional Flight
Aircraft Safe Drop
Accidental Release Safety
Sled

Table V summarizes the Phase II testing program. Table VI supplements Table V by summarizing the late-1965 program of environmental testing. Table V includes a column in which the corrective actions that were taken during the course of the testing are also summarized.

D. PHASE III EVALUATION PROGRAM

Two hundred two fuzes were subjected to environmental tests by the sponsor at the Eglin Air Force Base test facilities. Two groups of tests were conducted: flight and sled tests and environmental tests. The following Tables (VII, VIII, and IX) summarize the test data: dates, number of fuzes tested, and the results.

All of the failed fuzes and the majority of the "no test" items were analyzed by a failure-analysis team to determine the causes of the failures, or reasons for declaring a "no test". Table X summarizes the failure analyses and also provides a description of the corrective actions and their effectivities. Table XI summarizes the information about the fuzes declared "no test".

E. SUMMARY

By carrying out the comprehensive Phase I, II, and III evaluation programs, and by performing analyses of failures, corrective actions were taken to effect fabrication of fuze assemblies with reliabilities in excess of 0.9 at 90-percent confidence.

TABLE V. SUMMARY OF PHASE II TESTING PROGRAM

TEST	FUZE SERIAL NO. (NUMBER OF FUZES TESTED)	DATE(S) OF TEST(S)	RESULTS	
			NO. PROPERS AND OTHER DISPOSITION	FAILURE MODE(S); (UNITS AFFECTED)
OUT-OF-LINE SAFETY (MIL-STD-315)	(30)*	JULY '64	30	-
FUNCTIONAL (SIMULATED FLIGHT) ALL "COMMENTS AND/OR CORRECTIVE ACTIONS TAKEN" BELOW RELATE TO THIS TEST	101, 101R, 102, 103, 102R, 105, 104, 101R2, 102R2, 103R, 101R3, 102R3, 103R2, 105R, 107, 115, 115R, 118 111, 112, 116, 117, 113, 114, 119, AND 120 (26) (TEN UNITS WERE REBUILT AND RETESTED. SEE NOTE A.)	AUGUST THROUGH OCTOBER '64	4 (ONE PROPER, A SAFING PLUG TEST; 3 WERE REBUILT UNITS.)	PARTIAL ARM - (7) FAILED-TO-ARM - (3) FAILED-TO-EVENT - (2) EVENTED EARLY - (7) EVENTED LATE - (2) BATTERY FAILED TO ACTIVATE - (1)

COMMENTS AND OR CORRECTIVE ACTIONS TAKEN

(1) THE MUSIC WIRE DIAMETER WAS INCREASED TO 0.024 INCH DIAMETER AND THE BELLOWS ACTUATORS WERE CHANGED TO THE SLOWER-BURNING TYPE USED ON THE FMU-30 B FUZE. THIS ACTION WAS TAKEN TO PREVENT BREAKAGE OF THE PISTON WIRES AS A RESULT OF THE SHOCK LOADING AT ARMING. IN ADDITION, THIS CHANGE REDUCED THE ARMING SHOCK WHICH COULD CAUSE PREMATURE OPERATION OF THE IMPACT SWITCH. ELEVEN ARMING TESTS OF THIS CONFIGURATION AT -65°F (4 UNITS), ROOM TEMPERATURE (4 UNITS), AND 160°F (3 UNITS) WERE ALL SUCCESSFUL.

(2) THE PROCEDURE FOR ASSEMBLING THE ROTOR CONTACTS TO THE CONTACT RING WAS MODIFIED, AND ADDITIONAL INSPECTION PROCEDURES WERE INTRODUCED TO PREVENT DAMAGED SWITCH CONTACTS FROM REACHING FINAL FUZE ASSEMBLY.

(3) THE MYLAR TAPE USED TO HOLD THE ELECTRONIC PACKAGE LEADS DURING POTTING WAS REPLACED BY LACING CORD TO PREVENT FORMATION OF FAULT PLANES IN THE POTTED ASSEMBLY WHICH MIGHT HAVE SPLIT AT IMPACT.

(4) PLANS WERE FORMULATED FOR INCORPORATION OF THE REDESIGNED COUNTER CIRCUITS ON THE LAST 81 PHASE II FUZES TO IMPROVE THE RESISTANCE OF THE COUNTER TO SHOCK. THESE COUNTERS ALSO HAD IMPROVED OPERATING CHARACTERISTICS AT THE TEMPERATURE EXTREMES.

(5) THE FAILURE OF THE 1 BATTERY TO ACTIVATE WAS ATTRIBUTED TO THE USE OF AN IMPROPERLY ARMED PERCUSSION CAP. THE METHOD OF ARMING THE CAPS WAS MODIFIED, AND NO FAILURES OF THIS SORT OCCURED DURING SUBSEQUENT TESTS.

(6) THE BATTERY GAS GENERATOR WAS REDESIGNED TO PREVENT OR MINIMIZE EXPANSION.

(7) SPACERS WERE ADDED BETWEEN THE BATTERY AND EXPLOSIVE TRAIN TO ALLOW A MINIMUM OF 0.010-INCH BATTERY EXPANSION WITHOUT BINDING THE ROTOR.

(8) DEVELOPMENT EFFORT WAS INITIATED TO INVESTIGATE MEANS OF IMPROVING THE BATTERY SEALS TO PREVENT SEAL LEAKAGE, THE APPARENT CAUSE OF 1 BATTERY FAILURE.

(9) THE IMPACT SWITCH CIRCUIT WAS MODIFIED TO ELIMINATE THE NEED FOR ROTOR SWITCHING OF THE IMPACT SWITCH CIRCUIT.

(10) THE A-D SWITCH DESIGN WAS REVIEWED TO IMPROVE THE STRUCTURAL ADEQUACY OF THE MOLDED PARTS. IN ADDITION, THE MEANS OF ATTACHING THE SWITCH TO THE EXPLOSIVE TRAIN HOUSING WERE REVIEWED.

* THESE 30 FUZES WERE NOT NUMBERED.

NOTE A: LETTER R INDICATES FIRST REBUILD; R2, THE SECOND; AND R3, THE THIRD.

TABLE V. SUMMARY OF PHASE II TESTING PROGRAM (Continued)

TEST	FUZE SERIAL NO. (NO. OF FUZES TESTED)	DATES (S) OF TEST (S)	RESULTS		COMMENTS AND/OR CORRECTIVE ACTIONS TAKEN
			NO PROPERS & OTHER DISPOSITION	FAILURE MODES (S) (UNITS AFFECTED)	
FUNCTIONAL (SIMULATED FLIGHT) AND ENVIRONMENTAL	121, 122, 125 128-134, 136, 106, 109, 110 (14)	OCTOBER '64 THROUGH JUNE '65	2 (TEMPERATURE SHOCK TEST)	FAILED-TO-ARM OR PARTIALLY ARMED - (4) FAILED TO EVENT - (2) A-D SWITCH FAILED - (3) BATTERY FAILED - (2) IMPACT CIRCUIT FAILED - (1)	AS A RESULT OF DESIGN DISCREPANCIES NOTED IN THESE TESTS, THE PRODUCTION FABRICATION OF FMU-35/B FUZES WAS HALTED (4 NOVEMBER 1964) AND THE FOLLOWING ACTIONS TAKEN (1) DESIGN EFFORT WAS INITIATED TO REDESIGN THE FUZE EXPLOSIVE TRAIN TO PREVENT GROSS DAMAGE AT IMPACT, PREVENT DAMAGE TO THE ROTOR SWITCH AT IMPACT, AND IMPROVE THE METHOD OF ROTATING THE ROTOR-IN-LINE. (2) A FLIGHT TEST PROGRAM, INVOLVING 10 TECH.-LAB-BUILT FUZES WITH DUMMY ELECTRONICS AND BATTERY, WAS FORMULATED TO CHECK OUT THE REDESIGNED, MECHANICAL ASSEMBLIES (THESE UNITS WERE TO BE COUNTED IN THE PHASE II QUANTITY).
FLIGHT TEST	123, 124, 126 127 (4)	NOVEMBER '64	-	PARTIALLY ARMED - (3) FAILED-TO-EVENT - (1) (ALL 4 EXHIBITED EXPLOSIVE TRAIN DAMAGE.)	(3) PLANS WERE FORMULATED TO INCORPORATE THE IMPROVED COUNTERS IN THE ELECTRONIC ASSEMBLY UPON RESUMPTION OF THE PRODUCTION BUILD PROGRAMS. (4) PLANS WERE MADE TO INCORPORATE THE STRENGTHENED A-D SWITCH IN THE NEXT PRODUCTION FUZES. (5) ADDITIONAL EFFORT WAS APPLIED TOWARD IMPROVING THE BATTERY SEALS SINCE FAILURE IN THIS AREA WAS FELT TO BE THE CAUSE OF THE HUMIDITY-TEST FAILURES
FLIGHT TEST	1-10 (10)	DECEMBER '64 THROUGH FEBRUARY '65	8	SHORT BATTERY LIFE - (1) DROPPED SAFE - (1)	THESE FLIGHT-TEST UNITS CONTAINED MODIFICATIONS TO THE EXPLOSIVE TRAIN ENCLOSED ROTOR-SWITCH CONTACTS, ROUTED PISTON WIRES, FMU-30/B DETENT AND SPRING, STRENGTHENED ROTOR HOUSING, SILICON O-RINGS IN THE ROTOR, REDESIGNED BFD, AND REDESIGNED A-D SWITCH
SLED TEST	ONE OF ABOVE FLIGHT-TEST UNITS. (1)		1		TWO OF THE TEST UNITS CONTAINED E-CELL TIMERS AND WERE INVOLVED IN THE 2 FAILURES.
SHOCK TOWER AND TEMPERATURE	137-142 (6)	JUNE AND JULY '65	2	ELECTRONICS FAILURE - (1) COUNTER FAILURE - (1) A-D SWITCH FAILURE - (1) BFD FAILURE - (1)	(1) THE BASIC SIZE OF THE A-D SWITCH WAS REDUCED (PHASE II UNITS) TO REDUCE ITS MASS, AND SHRINK TUBING WAS ADDED TO INSULATE AND SUPPORT THE RING CONTACT. (2) THE LANYARD HOUSING WAS MODIFIED TO PREVENT RELEASE OF THE LANYARD BEFORE THE FIRING PIN WAS RELEASED. (3) NO ACTION WAS TAKEN ON THE ELECTRONICS FAILURES PENDING RESULTS OF THE FIRST FLIGHT TESTS.

NOTE ● FUZE SERIAL NUMBERS 108 AND 135 WERE NOT TESTED.

TABLE V. SUMMARY OF PHASE II TESTING PROGRAM (Concluded)

TEST	FUZE SERIAL NO. (NO. OF FUZES TESTED)	DATE(S) OF TEST(S)	RESULTS NO. PROPERS & OTHER DISPOSITION	 FAILURE MODE(S) (UNITS AFFECTED)	COMMENTS AND/OR CORRECTIVE ACTIONS TAKEN
FLIGHT	143-145, 147, 148, 150, 151, 154 (8)	AUGUST '65	3	A) BATTERY FAILED TO INITIATE - (2) B) BATTERY FAILED TO OPERATE - (3)	A) BATTERY FAILED TO INITIATE DUE TO LEAKAGE OF AMMONIA INTO GAS GENERATOR ASSEMBLY. LEAK CHECK OF ACTIVATOR SUBASSEMBLY AT 160 F WAS IMPLEMENTED TO CONTROL AMMONIA LEAKAGE.
SHOCK TOWER TEST	146, 149 152, 153 (4)	AUGUST '65	-	C) BATTERY FAILED TO INITIATE - (1) D) COUNTER FAILED - (2) E) ARMING FAILURE - (1)	B) PIN LOCKS RE-DESIGNED TO PREVENT JAMMING. C) ARMED B SHORTED TO THE BATTERY. AN INSULATOR WAS ADDED BETWEEN THE BATTERY AND THE ELECTRONICS. D) EVENT TIMES 10 SHORT CALIBRATION CHANGED AFTER SHOCK. E) COUNTER CIRCUIT SHORTED TO BATTERY. AN INSULATOR WAS ADDED BETWEEN THE ELECTRONICS AND BATTERY.
FLIGHT	176, 179, 180, 182-186 (8)	SEPTEMBER '65	3	A) BFD FAILURE - (2) B) COUNTER FAILURE - (3)	A) BFD's WERE MODIFIED TO INCLUDE REBUILT (MODIFIED) PIN LOCKS. B) BI-MAG COUNTER LOST SET AT IMPACT. CIRCUIT RE-DESIGNED TO CLEAR AND SET AFTER IMPACT.
ENVIRONMENTAL	155-165, 197-205 (20)	SEPTEMBER '65 THROUGH OCTOBER '65	(SEE TABLE VI WHICH COVERS ENVIRONMENTAL TESTS, EXCLUSIVELY.)		
LABORATORY FUNCTIONAL	166, 191 (2)	SEPTEMBER '65	2		THE FUZES TESTED HAD BEEN MODIFIED SO THE BIMAG COUNTER WOULD BE SET AFTER IMPACT RATHER THAN AT ARMING.
FLIGHT FLIGHT FUNCTIONAL SPRING-LOCK ADEQUANCY AIRCRAFT SAFE DROP	 171, 168, 173, 167 (4) 178, 181, 195, 196 (4) 175, 177, 187 (3)	OCTOBER '65	 1 - 3	A) EARLY EVENT - (2) B) BFD FAILURE - (1) C) SPRING LOCKS BROKEN - (4) D) FAILED TO ARM - (1 OF B)	A) EARLY EVENT RESULT OF BI-MAG NOISE. CHANGED DESIGN TO ELIMINATE NOISE. B) THIS BATTERY FIRING DEVICE HAD BEEN USED DURING THE STATIC EJECTION TESTS AND HAD BEEN REBUILT. DAMAGE IN THE FORM OF GROOVES IN THE LANYARD HOUSING PROBABLY OCCURRED AT THAT TIME. C) SPRING LOCKS RE-DESIGNED D) THE ARMING FAILURE WAS CAUSED BY THE P-C BOARD PREVENTING ROTOR ROTATION. ADDITIONAL MANUFACTURING AND QUALITY-CONTROL MEASURES WERE SPECIFIED.
FLIGHT	169, 170, 172, 174, 192-194, 206-208 (10)	NOVEMBER '65	6	A) ROTOR COULD NOT TURN - (1) B) BATTERY FAILURE - (1) C) FAILED TO EVENT - (2) ACTUAL EVENT TIME OF ONE COULD NOT BE DETERMINED	A) FLUX ON ROTOR P-C BOARD. ADDITIONAL MANUFACTURING AND QUALITY CONTROL MEASURES WERE SPECIFIED. B) BATTERY FAILED TO INITIATE DUE TO LEAKAGE OF AMMONIA INTO GAS GENERATOR TEST FOR LEAKS IMPLEMENTED INTO PRODUCTION PROCESS. C) FAILED TO EVENT DUE TO SHORTED DIMPLE MOTORS. INSULATION ADDED TO DIMPLE MOTOR WIRES.
ACCIDENTAL RELEASE SAFETY	188, 189, 190	NOVEMBER '65	2	INITIATED AT IMPACT AND ARMED - 1	FAILURE WAS CAUSED BY A WIRING ERROR.
STATIC FIRING	209, 210	DECEMBER '65	2	-	S/N 209 HAD A BUILT-IN LONG TIMING OF ABOUT 10.
GRAND TOTALS	139 EXCLUSIVE OF ENVIRONMENTAL TEST FUZES (20)		69	70	

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TABLE VI. SUMMARY OF PHASE II ENVIRONMENTAL TESTING DU

TEST	S N 155	156	157	158	159	160	161	162	163	164	16
INITIAL	FUZE TO CASE SHORT	F.T.A. 7 8 VDC F.T.A. AT 13 OR 30 HR	OK	OK	OK	F.T.A. 9.0 VDC	OK	F.T.A. 9.0 VDC	F.T.A. 9 0 VDC	OK	L.E. AT 2 3 SET
LOW TEMPERATURE				L.E. AT 2 3 SETTING	OK			F.T.A. 9 0 VDC	F.T.A. AT 2 3 SETTING	L.E. AT 2/3 SETTING	
POST LOW TEMPERATURE				OK				F.T.A. AT 2/3 SETTING	F.T.A. AT 2 3 SETTING	E DURING A-D TEST; NO REARMING	
HIGH TEMPERATURE			E.E. AT 2 3 SET-TING			OK	E.E. AT 2 3 SETTING	E.E. AT 2 3 SETTING			
POST HIGH TEMPERATURE			OK			F T.A. 9 0 VDC	OK				
POST THERMAL SHOCK											
POST TEMPERATURE AND HUMIDITY							OK				E.E. AT 2 3 SET
HIGH ALTITUDE											
POST HIGH ALTITUDE	OK										
JOLT										OK	
JUMBLE											OK
FORTY-FOOT DROP			OK	OK			OK	OK	OK		
FIVE-FOOT DROP											
MECHANICAL SHOCK AND FUZE ACTIVATION		E.E. AT 1-1 3 SETTING			F.T.E.	B+ WIRE BROKEN, L.E. 2 3 SETTING					
POST AIRCRAFT VIBRATION					FUZE NOT TIGHTLY HELD AGAINST B.F.D.	F.T.A. AT 2 3 SETTING, F.T.A. AT 9 0 V	FUZE HELD TIGHTLY AGAINST B.F.D. WITH SHIMS				
POST TRANSPORTATION VIBRATION			OK								L.E. AT 2 3 SET
POST IMMERSION				OK							
POST SALT SPRAY						F T A AT 9.0 VDC, F.T.E AT 30 SETTING					
ACOUSTICAL NOISE								OK	OK		
POST ACOUSTICAL NOISE									F.T.A. 8 6 VDC	F.T.A. 8 1 VDC	

II ENVIRONMENTAL TESTING DURING SEPTEMBER AND OCTOBER 1965

	161	162	163	164	165	197	198	199	200	201	202	203	204	205
	OK	F.T.A. 9.0 VDC	F.T.A. 9.0 VDC	OK	L.E. AT 2/3 SETTING	L.E. AT 2/3 SETTING	OK	OK	L.E. AT 2/3 SETTING	L.E. AT 2/3 SETTING			OK	OK
		F.T.A. 9.0 VDC	F.T.A. AT 2/3 SETTING	L.E. AT 2/3 SETTING										
		F.T.A. AT 2/3 SETTING	F.T.A. AT 2/3 SETTING	E DURING A-D TEST, NO REARMING										
	E.E. AT 2/3 SETTING	E.E. AT 2/3 SETTING												
	OK													
						SHORT BETWEEN PINS 1 AND 12								
	OK				E.E. AT 2/3 SETTING			E.E. AT 2/3 SETTING		F.T.A. 7.8 VDC IMPACT INDICATION				
								OK		L.E. AT 2/3 SETTING			OK	OK
								OK					OK	OK
				OK		OK								
					OK									
	OK	OK	OK					OK			OK		OK	OK
												OK		
E. G							FUZE ACTIVATED DURING TEST.		FUZE ACTIVATED DURING TEST.					
G,	FUZE HELD TIGHTLY AGAINST B.F.D. WITH SHIMS						a) SAME AS 161 b) L.E. AT 2/3 SETTING							
					L.E. AT 2/3 SETTING									
									CONTAINER LEAK, L.E. AT 2/3 SETTING					
G														
		OK	OK											
			F.T.A. 8.6 VDC	F.T.A. 8.1 VDC										

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TABLE VII. SUMMARY OF PHASE III FLIGHT TESTS

DATE OF TEST	NO. OF FUZES FLOWN	RESULTS			
		PROPERS	"NO TEST"	FAILED	ANALYZED
9 FEB '66	12	11		1	1
5 APRIL '66	12	8		4	4
15 APRIL '66	12	8		4	4
25 APRIL '66	12	10		2	2
2 MAY '66	8	8		-	-
18 MAY '66	12	7	1*	4	4
31 MAY '66	12	9		3	3
6 JUNE '66	12	8		4	4
27 JUNE '66	12	5	2**	5	6
30 JUNE '66	4	3		1	1
TOTALS	108	77	3	28	29

* BOMB DROPPED SAFE; NO FUZE ANALYSIS MADE.
** ONE OF TWO BOMBS DROPPED SAFE; NO FUZE ANALYSIS MADE.

TABLE VIII. SUMMARY OF PHASE III SLED TESTS

DATE OF TEST	RESULTS				
	NO. OF FUZES	PROPERS	"NO TEST"	FAILED	ANALYZED
16 TO 25 FEB. '66	8	4	1	3	4
19 JULY TO 5 AUG. '66	10	2	8	0	0*
TOTALS	18	6	9	3	4

* NO ANALYSES WERE MADE SINCE TWO BOMBS WERE LOST, FIVE BOMBS WERE BROKEN UP, AND THE EVENT TIME WAS UNKNOWN IN ONE FUZE.

TABLE IX. SUMMARY OF PHASE III ENVIRONMENTAL TESTS (15 MAY THROUGH SEPTEMBER 1966)

TEST		NUMBER OF FUZES TESTED	RESULTS			
			PROPERS	"NO TEST"	FAILED	ANALYZED
MIL-STD-300,	JOLT	6	6	-	-	-
301	JUMBLE	6	6	-	-	-
302	FORTY-FOOT DROP	5	5	-	-	-
303A	TRANSPORTATION VIBRATION	6	1	2	3	3
304	TEMPERATURE AND HUMIDITY	1	1	-	-	-
305	VACUUM-STEAM-PRESSURE	1	-	1	-	1
306	SALT SPRAY	2	1	1	-	1
307A	JETTISON (AIRCRAFT SAFE DROP)	4	4	-	-	-
311	ACCIDENTAL RELEASE	4	4	-	-	-
314	WATERPROOFNESS	2	1	-	1	1
315	STATIC DETONATOR SAFETY	7	7	-	-	-
324	FUNGUS RESISTANCE	7	5	2	-	2
327	THERMAL SHOCK	7	5	2	-	2
SAND AND DUST		7	5	2	-	2
STATIC EJECTION		4	3	1	-	1
ALTITUDE AND TEMPERATURE		7	7	-	-	-
TOTALS		76	61	11	4	13

TABLE X. FMU-35/B PHASE III FAILURE-ANALYSIS SUMMARY

FUZE S/N	F & A NO.	TEST DESCRIPTION	MODE OF FAILURE	CAUSE OF FAILURE	CORRECTIVE ACTION	EFFECTIVITY OF CORRECTIVE ACTION	
						AF 08 (635) 3745	AF 33 (657) 15400
431 446 474 525 554	35-154 35-152 35-170 35-170 35-212	FLIGHT SLED FLIGHT FLIGHT MIL-STD-303	FAIL TO ARM FAIL TO ARM FAIL TO EVENT FAIL TO EVENT FAIL TO ARM	NH_3 LEAKED FROM BATTERY DURING ASSEMBLY POTTING PROCESS REDUCING OR ELIMINATING THE BATTERY LIFE CAPABILITY.	ASSEMBLY POTTING TEMPERATURE CONTROLS PLUS ADDED SEAL CHECKS ON BATTERY.	FUZES BUILT AFTER 4-22-66	ALL UNITS
443 444	35-129 35-129	SLED SLED	FAIL TO EVENT FAIL TO EVENT	EVENT CAPACITORS SHORTED OUT DUE TO SOLDER BALLS FROM ASSEMBLY PROCESS.	1) ASSEMBLY SOLDERING PROCESS REVISED 2) EPOXY END FILLED CAPACITORS SPECIFIED.	1) UNITS BUILT AFTER 3-30-66 OTHERS RE-INSPECTED	1) ALL UNITS 2) UNITS BUILT AFTER 7-1-66
490 495 489 497 483 504 513	35-176 35-164 35-151 35-151 35-163 35-186 35-189	FLIGHT FLIGHT FLIGHT FLIGHT FLIGHT FLIGHT FLIGHT	PARTIAL ARM FAIL TO ARM FAIL TO ARM FAIL TO ARM FAIL TO ARM PARTIAL ARM FAIL TO ARM	PREMATURE ACTUATION OF THE SAFING SWITCH	1) SAFING SWITCH DESIGN MODIFIED TO PREVENT ACTUATION AS A RESULT OF EJECTION SHOCK 2) REVERSE THE LEADS TO THE SAFING SWITCH.	1) 174 FUZES 2) NONE	ALL FUZES 1 & 2
482 477 536 510 408	35-191 35-185 35-185 35-199 35-199	FLIGHT FLIGHT FLIGHT FLIGHT FLIGHT	EARLY EVENT EARLY EVENT EARLY EVENT LATE EVENT LATE EVENT	FAILURE COULD NOT BE DUPLICATED IN LAB. POSSIBLY DUE TO IN-COMPLETE CLEARING OF COUNTER CORES PRIOR TO SHIPMENT.	PROCESS REVISED TO CLEAR ALL COUNTER CORES SUBSEQUENT TO FINAL ASSEMBLY.	FUZES BUILT AFTER 22 APRIL 1966	ALL FUZES
503	35-171	FLIGHT	FAIL TO EVENT	DECADE COUNTER FAILED AT IMPACT	NONE PLANNED AT PRESENT - SEE FAR		
537 400 399 409 479	35-178 35-184 35-202 35-203 35-201	FLIGHT FLIGHT FLIGHT FLIGHT FLIGHT	FAIL TO EVENT EARLY EVENT FAIL TO EVENT FAIL TO EVENT LATE EVENT	TRANSISTOR FAILED IN ELECTRONIC PACKAGE AT IMPACT	INVESTIGATE EPOXY TRANSIS-TORS AS REPLACEMENT FOR FAILED COMPONENTS	NONE-FABRI-CATION COMPLETE BEFORE 5-27-66	TO BE DETERMINED
411	35-198	FLIGHT	FAIL TO ARM	BROKEN GROUND LEAD AT ROTOR P.C. BD.	NONE-PROCESS CONTROLS IMPROVED SINCE.	APPROX. 300 FUZES	ALL FUZES
539	35-205	FLIGHT	FAIL TO EVENT	BATTERY FAILED-SHORT LIFE	DEVELOPMENT EFFORT CONTINU-ING TO IMPROVE BATTERY LIFE		
401	35-190	FLIGHT	EARLY EVENT	COULD NOT BE DETERMINED-DECADE COUNTER FAILED AT EVENT	NONE-COUNTER CLEARING PRIOR TO SHIPMENT MAY HAVE PRE-VENTED EARLY EVENT.		
563	35-192	MIL-STD-314	FUZE LEAKED	CUT 'O' RING AT ROTOR & PITTED SURFACE	IN PROCESS CHECK TO DETECT LEAKING SEALS AND IMPROVED SEALS.	S/N 694 THRU 700	ALL FUZES
406	35-206	FLIGHT	FAIL TO ARM	BATTERY FIRING DEVICE FAILED TO INITIATE BATTERY.	NONE-BFD NOT RETURNED FOR ANALYSIS		
412 413	35-204 35-207	FLIGHT FLIGHT	EARLY EVENT EARLY EVENT	DECADE COUNTER SHIFTS COUNT AT HIGH TEMP.	NONE-PRODUCTION FUZES MEET CP56422 REQUIREMENTS		
410	35-213	FLIGHT	LATE EVENT	FAILURE DIDN'T REPEAT IN LAB.	NONE		
562	35-215	MIL-STD 303	PARTIAL ARM	SAFING SWITCH OPERATED PRE-MATURELY	NONE PLANNED TO DATE		
559	35-214	MIL-STD 303	EARLY EVENT	A.D. SWITCH DAMAGED IN VIBRATION	NONE PLANNED TO DATE		

TABLE XI. PHASE III "NO-TEST" SUMMARY

FUZE S/N	F & A NO	TEST	COMMENTS
407	35-209	FLIGHT	PARTIAL ARM DUE TO IMPROPER INSTALLATION
550	-	FLIGHT	DROPPED SAFE
542	-	FLIGHT	DROPPED SAFE
351	35-211	MIL-STD 324	WIRING ERROR
352	35-211	MIL-STD 324	WIRING ERROR
353	35-216	SAND & DUST	WIRING ERROR
355	35-211	SAND & DUST	WIRING ERROR
671	35-208	MIL-STD 327	TEST INSTRUMENTATION FAILED
678	35-208	MIL-STD 327	TEST INSTRUMENTATION FAILED
695	35-208	MIL-STD 305	TEST INSTRUMENTATION FAILED
696	35-208	MIL-STD 306	TEST INSTRUMENTATION FAILED
572	35-210	MIL-STD 303	IMPROPER INSTALLATION
555	-	MIL-STD 303	IMPROPER INSTALLATION
365	-	STATIC EJECT.	INSTRUMENTATION FAILURE
445	35-136	SLED	BOMB BROKE UP - DEFORMED FUZE
452	-	SLED	BOMB LOST
454	-	SLED	BOMB LOST
456	-	SLED	EVENT TIME UNKOWN
455	-	SLED	BOMB BROKE UP - DEFORMED FUZE
453	-	SLED	BOMB BROKE UP - DEFORMED FUZE
451	-	SLED	BOMB BROKE UP - DEFORMED FUZE
420	-	SLED	BOMB BROKE UP - DEFORMED FUZE
585	-	SLED	BOMB BROKE UP - DEFORMED FUZE

SECTION V

TECHNICAL DETAILS - RELIABILITY PROGRAM

During the course of the design and development of the FMU-35/B Bomb Fuze, particularly during Phase II and III, the reliability program involved the following: (a) analyzing the failures which occurred during the evaluation programs; (b) reporting on those analyses; and (c) recommending corrective actions. All of these activities appeared in failure-analysis reports that were attached to the monthly and weekly progress reports submitted to the sponsor. The corrective-action recommendations, accepted after concurrence with the design-engineering group, were translated into corrective actions. The component and circuit changes that were made are chronicled in Tables V and X found in the preceding sections of the report.

SECTION VI

TECHNICAL DETAILS - VALUE ENGINEERING PROGRAM

The value engineering program, conducted during the Phase I period of FMU-35/B design, provided an objective review of each design element aimed at achieving only necessary functions at minimum cost. Ten proposals were made in seven categories, and of these ten, four were incorpporated in the design. In the considerations for acceptance, proposals were assessed on the basis of the quantities of fuzes to be produced, and projected feasibility which would be based on the performance of laboratory and field evaluations. A recounting of the proposals made and the action taken is made in Table XII.

TABLE XII. SUMMARY OF VALUE-ENGINEERING PROPOSALS AND THEIR DISPOSITION

PROPOSAL DESCRIPTION	IMPLEMENTATION RECORD		
	YES (DATE)	NO-REASON(S)	COMMENTS
1 SIMPLIFICATION OF ELECTRONIC CIRCUITRY - A. REMOVE THE VOLTAGE SWITCHING CIRCUIT FOR THE ARMING OSCILLATOR AND USE ONLY THE SELECTED RESISTOR TO SET THE TIME DELAY.		INCORPORATION OF THIS MODIFICATION WOULD RESULT IN INCREASED TOLERANCE IN ARMING-TIME DELAY.	
B. REMOVE THE IMPACT SWITCH AND SCR NETWORK AND USE THE SAFING SWITCH FOR BOTH SAFING AND IMPACT SWITCH FUNCTIONS.		INCORPORATION OF THIS MODIFICATION WOULD REQUIRE REDESIGN OF THE EXPLOSIVE TRAIN TO ELIMINATE SHOCK AT ARMING.	
C. COMBINE THE FUNCTION OF THE SCR FOR THE CLEAR AND SET, BELLOWS, AND DETONATORS, THEREBY USING ONLY ONE UNIT FOR ALL FUNCTIONS.		THIS PROPOSAL WAS CONTINGENT UPON THE PREVIOUS PROPOSAL AND, THEREFORE ITS IMPLEMENTATION WAS REJECTED.	
2. SUBSTITUTE LOWER-COST CAPACITORS FOR ROLLED-CERAMIC CAPACITORS USED IN SEVEN PLACES.		LOWER-COST CAPACITORS WERE FOUND AND MET THE ELECTRICAL REQUIREMENTS. THERE WAS, HOWEVER, AN INCOMPATIBILITY WITH THE LIMITED VOLUME.	
3. ELIMINATE THE STAINLESS-STEEL INSERT IN THE CONTACT RING.	(15 FEB '64)		SUBSEQUENT REDESIGN OF THE EXPLOSIVE TRAIN TO IMPROVE STRUCTURAL CAPABILITY ELIMINATED THIS CONTACT ENTIRELY.
4. REDESIGN THE SETTING-KNOB SLIDER TO FACILITATE MANUFACTURE BY PUNCH PRESS.		(a) THE PROPOSED DESIGN WOULD HAVE BEEN DIFFICULT TO OPERATE AT LOW TEMPERATURES. (b) INSUFFICIENT STRENGTH WOULD HAVE NECESSITATED USING A HARDER MATERIAL. (c) A SAVINGS COULD NOT BE ANTICIPATED ON PRODUCTIONS LESS THAN 400 PIECES.	THE SETTING KNOB SLIDER WAS LATER CHANGED TO A DIE-CAST PART WHICH WAS MORE ECONOMICAL THAN THE PUNCH-PRESS PROPOSAL.
5. SIMPLIFY THE FIRING PIN BY REVISING THE DIMENSIONS, REMOVING THE HEAT-TREAT AND GRINDING REQUIREMENT, AND ELIMINATING THE TWO MILLED SLOTS.	(15 FEB '64)	CERTAIN OF DIMENSION CHANGES WERE INCORPORATED. HOWEVER, THE ELIMINATION OF THE HEAT TREATING AND GRINDING WAS REJECTED BECAUSE THE PARTS WERE THEN MORE SUSCEPTIBLE TO DAMAGE DURING HANDLING.	
6 ANTI-DISTURBANCE SWITCH - A. REDESIGN AND REVERSE THE CONTACT ARRANGEMENT		THE PROPOSAL WAS DEEMED TO BE UNFEASIBLE UNLESS A MUCH LARGER QUANTITY WAS PRODUCED.	
B. FABRICATE THE CONTACT CYLINDER BY EXTRUSION	(15 FEB '64)		THE DESIGN WILL FACILITATE THIS METHOD OF MANUFACTURE
7. USE A DECAL-TYPE MARKING FOR LABELING THE DIAL POSITIONS.	(15 FEB 64)		

SECTION VII

TECHNICAL DETAILS - E-CELL TIMER DESIGN, DEVELOPMENT, AND EVALUATION PROGRAMS

A. GENERAL

The contractor conducted a two-phase program to design, fabricate, and qualify an E-Cell timing concept for long-delay, bomb-fuze applications. Phase I was devoted to developing the timing concept and performing tests on the timer and its components to prove their ability to operate under the conditions experienced by tactically delivered long-delay bomb fuzes. Phase II was devoted to combining the E-Cell timing concept with the FMU-35/B Bomb Fuze and performing qualification-type tests on the resulting fuze. Figure 45 compares the electronic subassemblies of the FMU-35/B and the prototype FMU-63/B fuzes. It also points up the considerable reduction in the number of electronic components in the FMU-63/B fuzes. The FMU-35/B packaging (Figure 44) was adapted for the FMU-63/B.

B. DESIGN CRITERIA

The E-Cell timing concept and hence the FMU-35/B E-Cell Bomb Fuze, later designated FMU-63/B Bomb Fuze, was designed to meet the following functional requirements:

- Be settable from one hour to 72 hours.
- Have a time sequence initiated at impact.
- Have an event delay accuracy of ± 5 percent of set value.
- Possess an event-time backup of 100 hours.
- Cause bomb detonation if the fuze battery voltage degrades to a minimum usable level.

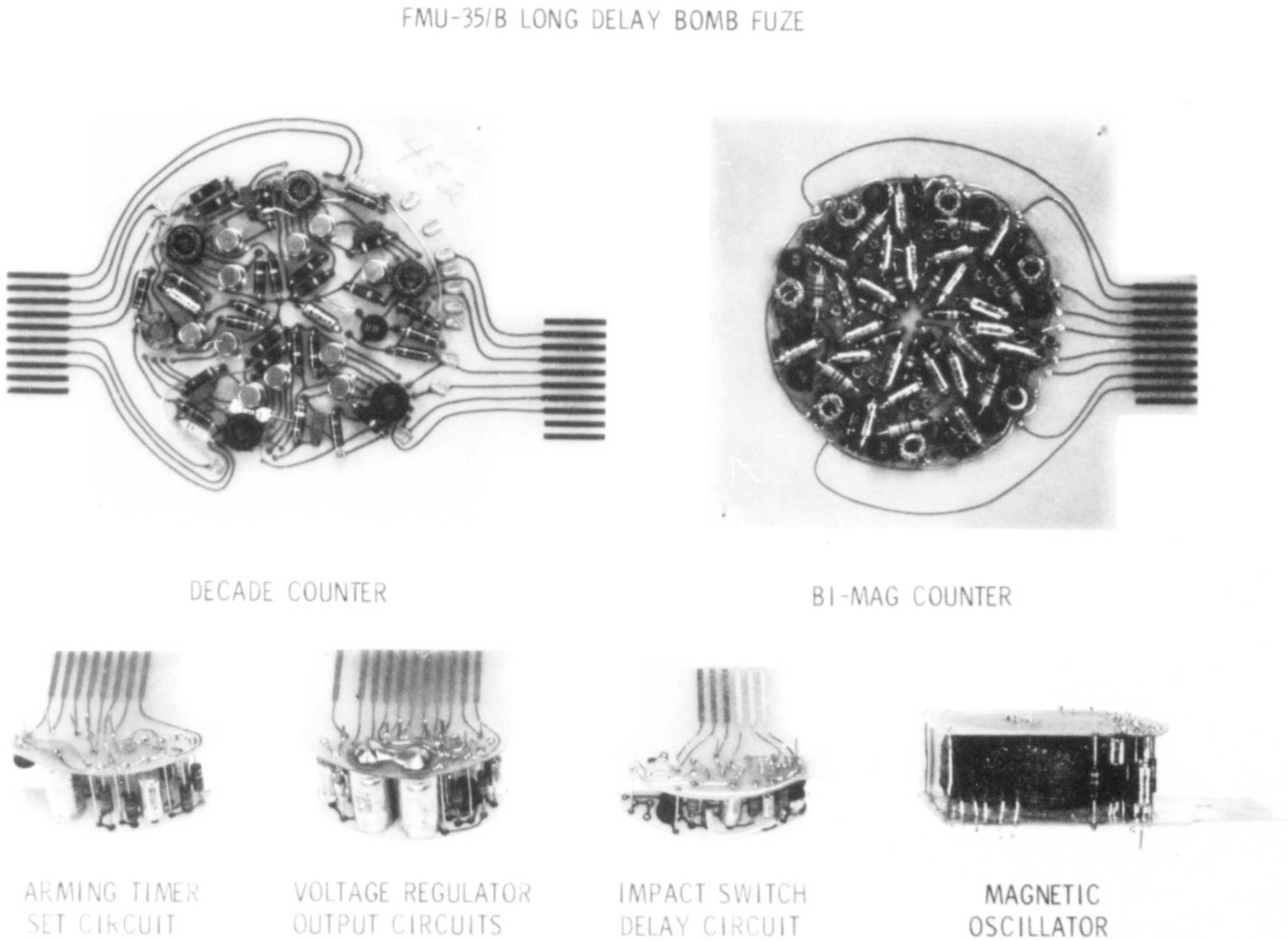

Figure 45. Comparison of FMU-35/B and FMU-63/B Electronics Subassemblies

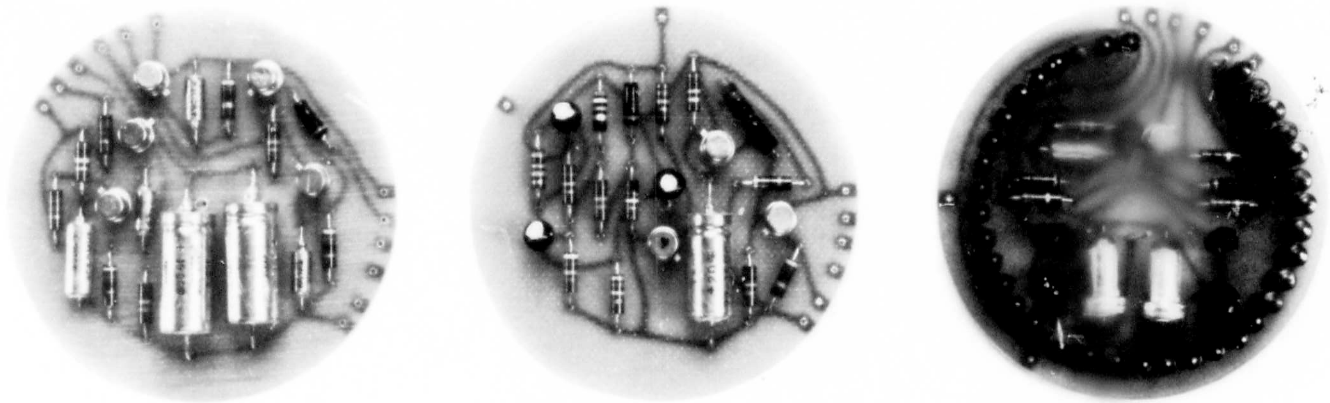

Figure 45. Comparison of FMU-35/B and FMU-63/B Electronic Subassemblies (Concluded)

- Possess an anti-disturbance feature which will prevent dearming and withdrawal of the fuze prior to the set event time.
- Operate from -65°F to +160°F.
- Operate at mechanical shock levels experienced by the M117 Bomb under tactical condition.
- Be completely compatible with the applicable FMU-35/B subassemblies.
- Have a system storage life of 10 years.

C. DEVELOPMENT TESTING

During the development phase of the E-Cell Timer Development Program, 25 E-Cell Timer Flight Systems, each system containing three separate E-Cell Timers, were fabricated. These 75 E-Cell Timers were flight tested at Eglin Air Force Base. Fifty-three E-Cell Timer tests were also conducted to determine the timer's ability to operate under, or after, various environmental conditions. Table XIII summarizes the Phase I tests and the corresponding results.

1. Flight Testing of E-Cell Timer

Seventy-five E-Cell Timers were flight tested during the development phase. The timers were set to various delay times from one to 72 hours to determine the effects on timing rate of environmental parameters associated with flight and bomb drop. Seventy-three timers functioned within the specified tolerance of ± 5 percent. One no-test condition resulted when the timer was not recovered until after the set time. The timer had functioned and post-flight analysis indicated that the timer was capable of repeated proper operation. Failure analysis revealed the short time out to be due to a combination of a wrong-value timing resistor, an improperly cured potting compound, and the deficiency of silver on the E-Cell anode.

The cause for the deficiency of silver on the E-Cell anode could not be identified positively. Either the E-Cell was built that way, or the improper testing of the timer caused some plating action to occur.

2. Low Temperature Operation

Ten tests were performed on the E-Cell timer at -65°F to determine its ability to operate within the specified tolerance at this low-temperature extreme. The timer functioned within ± 5 percent in all tests. All 10 timers functioned within the specified ± 5 percent.

TABLE XIII. E-CELL TIMER TEST RESULTS

Test	Total Timers Tested	Total Failures	No Test
Flight Testing	75	1	1
Low-Temperature Operation	10	0	0
High-Temperature Operation	10	0	0
Room-Temperature Operation	8	0	0
MIL-STD-304	5	0	0
MIL-STD-327 (Unpotted)	5	5	0
MIL-STD-327 (Potted)	10	1	0
High-Temperature Storage	5	0	3
Battery-Life Testing	5	1	0

3. High-Temperature Operation

Ten tests were performed on the E-Cell timer at +160°F to determine its functional properties at this temperature. All timers functioned within the specified ± 5 percent.

4. Room-Temperature Operation

Eight tests were performed on the E-Cell timer at room ambient. All timers functioned within the specified ± 5 percent.

5. Temperature-Humidity Testing (MIL-STD-304)

Five E-Cells were submitted to temperature-humidity testing per MIL-STD-304. All timers functioned within the specified ± 5 percent.

6. Thermal Shock (MIL-STD-327)

Fifteen E-Cells were submitted to thermal-shock testing of three cycles from $-55^{\circ}C$ to $+71^{\circ}C$. Five cells were unencapsulated and ten cells encapsulated.

From the results, it was obvious that the E-Cells must be encapsulated in order to pass thermal shock. No definite reason could be given for the one failure (Cell #10) in the encapsulated state.

7. High-Temperature Storage

Five E-Cells were submitted to high-temperature storage tests to determine their ability to withstand long periods of storage. Two cells passed the test, and there were three "no tests".

8. Battery-Life Tests

Five ESX8184 liquid-ammonia batteries were tested at room temperature to determine their operational life time to 7.2 vdc, based on a 5 milliampere drain at 9.0 vdc. Four batteries exceeded the expected 72-hour life. One battery failed due to an internal short.

D. QUALIFICATION TESTING

During Phase II of the E-Cell Timer Development Program, 20 fuzes using E-Cell Timers were fabricated. Qualification tests were performed in accordance with the Qualification Test Schedule, Table XIV. Sixty-five tests were performed on the fuzes to determine their ability to operate under or after various environmental conditions. Twelve fuzes were flight tested at Eglin Air Force Base, after the previous environmental tests, to prove the tactical capability of the fuze. Tables XV and XVI summarize the Phase II tests and the corresponding results.

1. Environmental Test Results

Sixty-five environmental tests were performed on the 20 fuzes fabricated in Phase II. The results are shown in Table XV. A description and an analysis of the failures are given below.

Fuze S/N 12 was tested at Eglin Air Force Base in May 1966 at $+160^\circ$F. The fuze was set for a 24-hour event delay. The fuze evented at 10 hrs, 18 min on low-voltage self-destruct, with a battery voltage of approximately 5.8 vdc. The E-Cell timer functioned at 29 hr, 18 min due to the low-battery voltage.

Fuze S/N 9 was initiated in July 1966 at the contractor's facility under room-temperature conditions. The fuze was set for an event delay of 46 hours.

The fuze only partially armed. Failure analysis of the fuze revealed that the failure was caused by the battery firing device not being held tightly into the fuze until the arming command appeared. The rotor momentarily hung up on the battery firing device, expending most of its energy before turning approximately 30 degrees. This failure was, therefore, due to the test method and does not reflect fuze design.

TABLE XIV. E-CELL BOMB FUZE QUALIFICATION - TEST SCHEDULE

TEST	FUZE S/N																			
	1	2	3	4	5	9	7	8	6	10	11	12	13	14	15	16	17	18	19	20
TRANSPORTATION VIBRATION							1			1			1			1			1	1
AIRCRAFT VIBRATION								1			1			1			1		2	2
HIGH TEMPERATURE		2		2				3		3	2*	2*	2*	2*		2		2		
LOW TEMPERATURE	2		2		2				2		2*	2*	2*	2*	2		2			
TEMPERATURE-HUMIDITY	1	1	1	1	1															
THERMAL SHOCK								2	1	2									3	3
ALTITUDE & ALTITUDE CHANGE						1						1			1			1		
ELECTROMAGNETIC SUSCEPTIBILITY						3	3													
ACOUSTICAL NOISE						2	2													
FLIGHT		3		3	3			4	3	4					3	3	3	3	4	4
LAB FUNCTIONAL	3					4	4													
BATTERY LIFE			3								3			3						

*HIGH AND LOW TEMPERATURE TESTS ON THESE UNITS WERE PERFORMED AT EGLIN AIR FORCE BASE.

NOTE: NUMERALS 1, 2, 3 AND 4 IN THE TABLE COLUMNS REFER TO TEST SEQUENCE.

TABLE XV. PHASE II ENVIRONMENTAL TEST RESULTS

TEST	TOTAL TESTS	TOTAL FAILURES	NO TEST
TRANSPORTATION VIBRATION	6	0	0
AIRCRAFT VIBRATION	6	0	0
TEMPERATURE-HUMIDITY	5	0	0
THERMAL SHOCK	5	0	0
ALTITUDE-ALTITUDE CHANGE	4	0	0
ELECTROMAGNETIC RADIATION	2	0	0
ACOUSTICAL NOISE	2	0	0
HIGH-TEMPERATURE OPERATION	10	1	0
LOW-TEMPERATURE OPERATION	19	6	0
LAB. FUNCTIONAL	3	1	0
BATTERY LIFE	3	0	0

Six out-of-tolerance timeouts at -65°F occurred during this phase. These failures seemed to be due to an insufficient volume of electrolyte in the cell at -65°F. The cells that failed at -65°F were returned to room temperature for analysis purposes. When current was supplied to the cell, a normal pretimed-out state existed. The capacity (in μAhr) remaining on the cell, under test, corresponded exactly to the capacity error at -65°F. Further testing revealed that at -65°F, the failed cells would indicate a timed-out state in one physical position and as the cell was moved, a normal pretimed-out state would occur. The vendor was notified of these results. He found that their low-temperature testing displayed the same effect and acted to eliminate it. The cells used in the low-temperature tests were partially filled with electrolyte at room temperature to allow room for electrolyte expansion at high temperature. The control of this process had been such that a large void resulted at low temperature, causing the indicated behavior. The problem was solved by filling the cells full at high temperature.

2. Flight Test Results

Twelve fuzes were flight tested at Eglin Air Force Base, after previous environmental tests, to prove the tactical capability of the fuze. The results are shown in Table XVI. Two fuzes failed to arm.

Fuze S/N 12 was flight tested at Eglin Air Force Base in June 1966. The fuze was set to event on the low-voltage, self-destruct feature. It was recovered unarmed. Analysis indicated that the battery did not initiate when struck by the firing pin of the battery firing device. X-rays verified this anlaysis. Further investigation revealed that the Mylar barrier in the gas generator had cracked. This crack allowed out-gassing, rendering the propellant inactive.

Fuze S/N 10 was flight tested at Eglin Air Force Base in May 1966. The fuze was recovered in the unarmed condition. The battery firing device

TABLE XVI. PHASE II FLIGHT TEST RESULTS

	TOTAL	REMARKS
FUZES TESTED	12	
FUZES ARMED	10	
FAILED TO ARM	2	ONE BATTERY FIRING DEVICE FAILURE ONE BATTERY FAILURE
FUZES EVENTED	9	EIGHT EVENTED PROPERLY ONE FUZE WAS NOT RECOVERED UNTIL AFTER SET TIME. EVENT HAD OCCURRED.
NO TEST	2	ONE FUZE WELL BROKE LOOSE FROM THE BOMB, SEVERELY DAMAGING THE FUZE.
FAILED TO EVENT	0	

had failed to initiate the battery, due to insufficient impact energy of the firing pin. An assembly error was found to be the cause of this failure.

Flight testing revealed a problem in the structural integrity of the selector-switch cover. Three selector-switch covers broke on fuzes tested under maximum impact shock, but all three switches maintained electrical contact until the fuze was removed from the bomb. A steel plate, which fits over the setting knob on the switch, will be used in future fuze testing to eliminate this problem.

E. SUMMARY

During the program to develop an E-Cell timing concept for long-delay, bomb-fuze applications, 193 tests were performed: 128 development tests and 65 fuze qualification tests. There were 12 failures: nine out-of-tolerance operations over the operating temperature range and three failures to arm. Table XVII illustrates the above data. Ten failures were directly attributed to quality control which should improve under normal production-type conditions. One failure was due to improper test methods and was declared a "no test". One failure, early time-out after MIL-STD-304 Temperature Humidity, was the only unexplained condition that occurred during this program.

TABLE XVII. SUMMARY OF RESULTS

	TOTAL	CAUSE(S) FOR FAILURE
TESTS CONDUCTED	193	
DEVELOPMENT TESTS	128	
FUZE QUALIFICATION TESTS	65	
SUCCESSFUL TESTS	181	
FAILURES	12	
FAILED TO ARM	3	ONE BY TEST METHOD (NO TEST.) TWO THROUGH POOR QUALITY CONTROL.
FAILED TO EVENT	0	
EVENTED EARLY	9	EIGHT THROUGH POOR QUALITY CONTROL. ONE UNKNOWN.

SECTION VIII

CONCLUSIONS AND RECOMMENDATION

A. CONCLUSIONS

Upon completion of Contract AF 08(635)-3745, the contractor had

1) Successfully designed and developed the FMU-35/B Long-Delay Bomb Fuze,

2) Taken corrective action after evaluation and failure-analysis programs to provide a fuze with a reliability in excess of 0.9 at 90-percent confidence, and

3) Accomplished the design and development of an E-Cell timer concept for application to the electronic, long-delay bomb fuze.

B. RECOMMENDATION

The following justify recommending that the E-Cell concept, as applied to long-delay bomb fuzes, be pursued further:

1) Simplicity of timer-subassembly design,

2) Successes experienced in the development, and

3) Projected high reliability.

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13. ABSTRACT

Under Contract AF 08(635)-3745, initiated on 17 June 1963, an electronic, long-delay bomb fuze, the FMU-35/B, was to be designed, developed, fabricated, and evaluated. By its development, the inherent disadvantages of the mechanical fuze, viz., unsuitability for supersonic flights and deliveries, low reliability, and potential safety problems were to be overcome. In the design and development of the fuze, those subassemblies of the existent FMU-26/B Bomb Fuze generically common to the FMU-35/B Bomb Fuze were modified, where necessary, for adaptation in the latter configuration. Through comprehensive programs of development, qualification, and Air Force engineering evaluation tests and through a comprehensive failure-analysis program, it has been possible to fabricate a long-delay fuze possessing a reliability in excess of 0.9 at a 90-percent confidenc level. Concomitant with the engineering-evaluation program (Phase III), an E-Cell concept for adaptation to the FMU-35/B fuze was designed and developed. The innate simplicity of the E-Cell timer as a substitute for the electronic-timer subassembly in the FMU-35/B, and its initial evaluative successes justify further consideration of the E-Cell concept.

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Fuze environmental testing						
Fuze flight testing						
Fuze reliability						
E-cell timer						